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Figure 1. James W. Abert, 1864. Source: LOC Photographs and Prints Division.

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Scientists of Kentucky

James W. Abert (1820–1897): Artist, Naturalist, Land Developer, and Topographical Engineer

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ABSTRACT

James W. Abert was an important explorer and scientist who called Kentucky home during the 1850s and for most of the period following the Civil War. At various times in his life Abert served as a government explorer in the southwest, an engineer for Ohio River navigational improvements, a military topographical engineer in the Mexican, Seminole, and Civil wars, a U.S. Examiner of Patents, a professor at two universities, and a land developer in northern Kentucky. His important contributions to the nation and to the state are often overlooked by scholars.

INTRODUCTION

Nineteenth-century Kentucky citizen James W. Abert was a figure of importance to the nation as well as to the commonwealth. During the 1840s, Lt. Abert conducted valuable surveys of the American southwest to reconnoiter the region's plants, animals, topography, and cultural resources for the United States government. These explorations led to the first scientific mapping of New Mexico and the Texas panhandle, as well as to the collecting of biological specimens for the fledgling Smithsonian Institution (seven species and one family were named for Abert). During the 1850s, he married into Kentucky's prominent Taylor family and was transferred to Louisville, from where he was promoted to captain and supervised numerous navigational improvements along the Ohio. During the Civil War, Cpt. Abert was Union Maj. Gen. Nathaniel Banks's chief topographical engineer for the 1862 Shenandoah Valley Campaign; later he supervised construction of fortifications and artillery emplacements to support operations in coastal Virginia, the Carolinas, and Georgia. Following the war, Abert served as U.S. Examiner of Patents and as a professor at the University of Missouri and at the Missouri School of Mines. After a few years in academia, Abert returned to his home in Newport, Kentucky, and proceeded to develop Cincinnati's Kentucky suburbs out of his father-in-law's vast land holdings.

ABERT'S EARLY LIFE

Other than scattered sketches and accounts of his western explorations (Carroll 1941a, 1941b; Galvin 1966, 1970; Goetzmann 1959; Morris 1999; Reis 2000; Ronda 2003; Tyler 1996), there is no published biography of James William Abert. As a result, the following summary of Abert's life relies heavily on the resources contained in the unpublished Abert Collections at the Filson Historical Society, Louisville, and at the University of Missouri–Rolla Archives (hereafter UMR). Abert was born in Mount Holly, New Jersey, on 18 Nov

1820 to Maj. John James Abert and Ellen Matlock (Stretch) Abert. Figure 1 reproduces a previously unpublished Civil War-era photograph of Abert.

Abert's paternal grandfather immigrated from France during the Revolutionary War (Mann n.d.). Abert's father, John J. Abert, was a career staff officer and the army's chief topographical engineer who successfully maneuvered the political trip wires necessary to gain an independent Corps of Topographical Engineers in 1838. As head of army topographers, it was John J. Abert who planned, supervised, and occasionally conceived the great official exploration and mapping of the Louisiana Purchase, Oregon, and former Mexican territories. Abert Lake in Oregon is named for him in tribute to his efforts to organize the expedition that led to its discovery.

Because of his father's position, Abert was reared in Washington, D.C., and enjoyed the best culture and education the nation's capital could then offer. He attended the Select Exclusive Seminary in Washington under the sponsorship of Salmon P. Chase (Hughes 1937). Entering Princeton's sophomore class at the age of 15, Abert graduated 3 years later, in 1838. Abert's interest in natural history blossomed at Princeton, where he first impressed Professor Joseph Henry (Henry 1869), distinguished physicist and later the first Secretary of the Smithsonian Institution. Immediately upon graduation from Princeton, Abert entered the U.S. Military Academy, from which he graduated 55th out of the 1842 class of 56 (Goetzmann 1959). Because of his unimpressive West Point credentials, Abert was assigned to infantry duty in Detroit until May 1843, when his father was able to secure for him a transfer to the Corps of Topographical Engineers. Abert spent 1843–1844 apprenticing in the field with Joseph Nicollet's extensive Great Lakes and upper Mississippi surveys. He then drafted maps for a year at the topographical corps headquarters in Washington.

EXPLORING THE FRONTIER

Abert's contribution to Manifest Destiny through his scientific and economic surveys of the southwest has been largely overlooked by historians, for whom he tends to be merely the subordinate of the prominent army geographers who dispatched him to his surveys: Cpt. John C. Frémont and Cpt. William H. Emory. This thinking tends to overlook the importance of Abert's mapping activities and the scale of his data collection, which was fundamental to a growing scientific appreciation for the geography and natural resources of the American southwest. This paper asserts that Abert was an important explorer-naturalist who led independent expeditions as part of a broader government initiative in the first half of the 19th century. Further discussion of the culture of official exploration during this period can be found in Goetzmann (1959), Ronda (2003), and Traas (1993).

In summer 1845 Abert joined Frémont's third expedition then assembling at St. Louis. Because Frémont's previous expedition had strayed considerably from its purpose, it is likely that the elder Abert assigned his son to the third expedition in an effort to reduce the threat of similar insubordination this time. However, in early August when Abert arrived at Bent's Fort in present-day southeastern Colorado, Frémont commenced to divide his command into two exploring parties. Frémont's larger and better-equipped group would proceed west to conduct a survey of the Great Basin and, eventually, to participate in the Bear Flag Revolt and the U.S. occupation of California. Setting out on 12 August, Abert's party headed south to explore "Purgatory Creek, [and] the waters of the Canadian and False Washita" rivers eastward to Indian territory in what is now Oklahoma (Abert 1846). Abert's detachment served several important purposes. Perhaps most significant for Frémont, the expedition disburdened him of his superior's son and of Lt. William G. Peck, the only army officers accompanying him and, therefore, the only people in a position to censure him for violating his orders by entering California. According to Isaac Cooper's journal, published under a penname, Frémont also sent all his malcontents along with Abert (des Montaignes 1972). But Abert's survey had broader purposes than simply to relieve Frémont of undesirables, for the mission fulfilled the Congressional mandate that had authorized Frémont to take the field in the first place. As originally authorized, Frémont's expedition was part of Missouri Sen. Thomas H. Benton's plan to survey the various potential

railroad routes to the west coast (Abert 1876). Furthermore, since Abert's line of march passed through Kiowa and Comanche territories, he was expected to reconnoiter these potentially hostile enemies of U.S. westward expansion, taking note of the region's natural resources along the way. Finally, Abert would also test the viability of the valley of the Canadian as a wagon route to Santa Fe. During his journey Abert was expected to collect scientific specimens and observations to be examined by armchair academics in the east (at this time it was not customary for scientists to collect their own data in the field). Lt. Abert's first independent command was therefore multifaceted in purpose.

Included among Abert's party were several highly experienced mountain men who greatly eased the burden of command. While Thomas "Broken Hand" Fitzpatrick assumed functional leadership of the team, Abert also enjoyed the services of experienced traders and trappers John Hatcher and Caleb Greenwood. This arrangement was sensible, productive, and amenable to all, as discussed in Abert (1846), des Montaignes (1972), and Hafen (1973). This situation afforded Abert and Peck greater opportunity to take astronomical observations and otherwise perform their scientific mission. The expedition's basic mapping obligation was hampered by a scarcity of appropriate equipment, since Frémont could only spare one compass, one sextant to determine latitude, one chronometer to determine longitude, and no barometer for estimating altitude—a great deficiency in a railroad survey.

From Bent's Fort, Abert followed the Santa Fe Trail southwards into New Mexico through the Raton Pass. Crossing to the headwaters of the Purgatory River, Abert descended roughly south to that stream's confluence with the Canadian. Shortly after that juncture the Canadian turns sharply east and Abert's route met with the Comanchero Trail out of Santa Fe, which vague trace he followed to the Cross Timbers region of the Texas-Oklahoma borderlands. From there they traveled to Ft. Gibson around present-day Oklahoma City, where the party was resupplied and refitted with wagons and animals for the march to St. Louis through western Arkansas and southern Missouri (camping, incidentally, in the vicinity of Rolla [Abert 1876], where a quarter century later Abert would chair a university engineering department).

Overall the mission was quite successful, although circumstances prevailed to hinder the full development of the expedition's scientific potential. The presence of a band of white men in their territory who occasionally started prairie fires through careless camping habits necessarily excited interest among the natives along their route. Their progress was continually shadowed by the various groups of Pawnee, Kiowa, Comanche, and Kaw whose summer ranges they intruded. This intense surveillance encouraged vigilance among Abert's party, and Fitzpatrick instituted a policy of camping behind a "kraal" (corral) of felled timbers and circled wagons (Abert 1846). Abert's expedition is the first time this innovation was employed by a government party in potentially hostile territory.

Whenever possible Abert invited the Indians who neared camp to eat, talk, and trade for tobacco. Abert was even invited to visit Kiowa and Comanche villages. He used these opportunities to gather cultural, linguistic, population, and military data on these likely enemies of the United States, which intelligence he conveyed in his report to Congress. Abert's (1846) report was the first information on the Kiowa and Comanche collected in the field by a U.S. government agent (Goetzmann 1959).

The expedition's scientific goals were hampered by the presence of potentially hostile natives, which prevented anyone from straying too far from camp to search for appropriate specimens. In accordance with the mission's primary purpose, Abert took the necessary astronomical observations to reckon their geographic position on each day that atmospheric conditions permitted suitable readings (these coordinates are dutifully recorded in his report). From these data Abert drafted the first scientific map of the Canadian route from central Oklahoma to Santa Fe, which is reproduced in Galvin (1970). Abert's work was the basis for all mapping of this region until the Southern Pacific Railroad was finally built following the Civil War. Abert's report occasionally mentions preserving an animal pelt, but there is no record of the plant, animal, and mineral samples that Abert collected on this expedition.

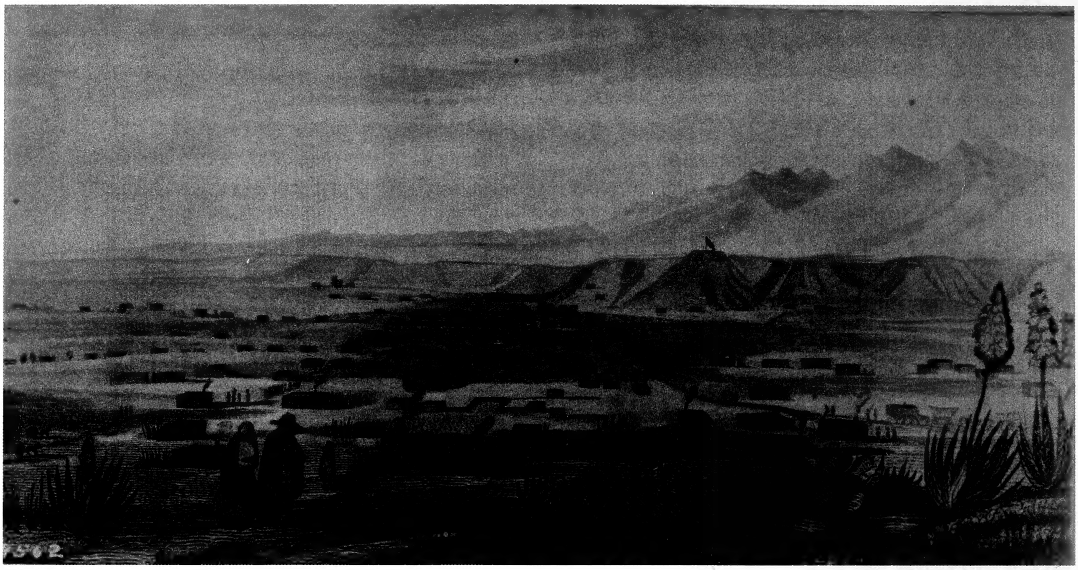

Figure 2. James W. Abert's drawing of Santa Fe, New Mexico, in 1847. Source: LOC Photographs and Prints Division.

Shortly after completing his report of the survey of Comanche country, Abert again went west, this time to join Col. Stephen W. Kearney's invasion of New Mexico as part of the war against Santa Ana. En route to join Kearney's command, Abert fell ill and had to recuperate at Bent's Fort while the army proceeded to take Santa Fe unopposed. By the time Abert arrived at Santa Fe, Kearney was on his way to California. Abert was ordered to make a map and thorough reconnaissance of the settled regions of the new U.S. territory of New Mexico.

While Abert was still recovering at Bent's Fort, Peck surveyed the vicinity of Taos and assisted Emory, their superior, in his collection of coordinate and altitude data for important locales in and around Santa Fe. When Abert arrived, he surveyed the Rio Grande valley and into the Hopi and Navajo lands west of the capital. Abert's report to Congress of the New Mexico survey includes numerous sketches (such as Figure 2) and watercolors, as well as Abert's impressive *Map of the Territory of New Mexico,* reproduced as Figure 3. This map served as the basis for topographic knowledge of most of New Mexico until it was surpassed by new government surveys following the Civil War.

As important as Abert's map was to providing accurate topographic information about the nation's new territory, it was in his role as field naturalist that he made his greatest contribution to scientific knowledge of New Mexico and northeastern Arizona. Abert's report is replete with macabre scenes of his topographer's field wagon rolling across the plains with an assortment of pelts, skins, and taxidermed critters drying on its canvas roof. As a result of Abert's aggressive efforts, his New Mexico exploration collected specimens of 15 mammals, 13 birds, and 179 plant species. Of these, Abert discovered—and recognized it at the time—3 new mammals, 2 new birds, and 25 new plant species. These samples were delivered to the Smithsonian Institution, where they were examined and their descriptions published by formal scientists. Abert also collected samples of 16 minerals to be evaluated for their economic potential, including gold and silver ores from New Mexican mines. A complete list of the specimens Abert collected appears in Appendix A of Galvin (1970).

Abert's efforts as a field naturalist impressed the scientists in Washington and Philadelphia, who named an entire family of fossil sand dollars (Abertellidae) and seven species after him: *Abertella aberti* (a fossil echinoid), *Ammophila aberti* (a thread-wasted sand wasp), *Cyprogenia aberti* (western fantail mussel), *Eriogonum abertianum* (Abert's wild buckwheat), *Pipilo aberti* (Abert's towhee), *Sanvitalia abertii*

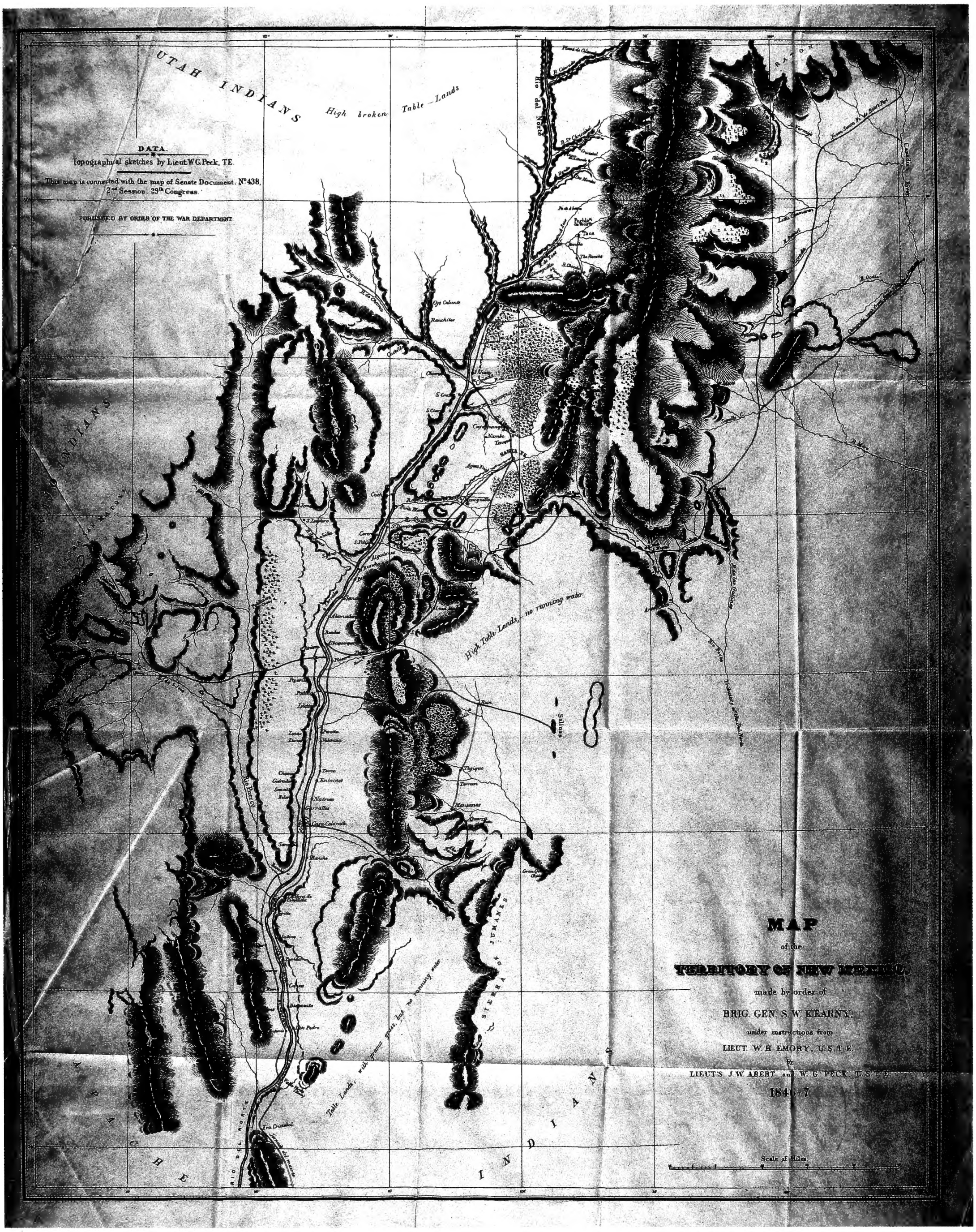

Figure 3. James W. Abert's map of the territory of New Mexico. Source: J. Willard Marriott Library, University of Utah.

(Abert's creeping-zinnia), and *Sciurus aberti* (Abert's tassel-eared squirrel).

Abert's orders for the New Mexico exploration instructed him to survey the territory's cultural resources as well. Specifically, he was ordered to search for the Seven Cities of Cibola mentioned in the Spanish chronicles of exploration. Abert correctly deduced Coronado's line of march to have been up the Puerco River to the San Jose Valley pueblos of Cibolleta, Moquino, Pajuate, Covero, Laguna, Rita, and Acoma (Goetzmann 1959). Of the six surviving settlements, only Acoma impressed Abert. Unfortunately for history's opinion of Abert's anthropological acumen, he accepted Alexander von Humboldt's belief that the Anasazi-built environment represented the remains left behind by Aztecs as they gradually migrated southward into the Valley of Mexico. By contrast, both Albert Gallatin and Abert's immediate superior, Emory, believed that the Anasazi were simply the ancestors of the Hopi and Pueblo groups inhabiting the region in modern times. Even as late as the end of the 19th century, Abert persisted in his belief in the Aztec hypothesis, as expressed in his paper on "The Indians of North America" (Abert 1890) and as inferred from two other academic publications about the Aztec introduced in a later section of the present paper.

If Abert were old-fashioned in his convictions about the Anasazi, one observation he made during the exploration was on the cutting edge of science. During the expedition he collected some coal and fossils from a Permian coal bed west of the Continental Divide that he realized matched other fossils he had encountered on his previous expedition through a Permian coal bed to the east of the Rockies. Abert correctly surmised that this indicated the coal bed predated the emergence of the mountains and that the swampy lowlands that had once characterized the prairie to the east once also extended to his location west of the Continental Divide. Abert announced this theory in his official report of the expedition (1848), and thus is one of the first Americans to recognize evidence of landform evolution as interpreted by modern geology. A similarly sophisticated understanding of surface and subsurface processes pervades both Abert's official report (1848) and his private journal of the expedition (Abert 1966).

Following these protracted surveys, Abert enjoyed a brief assistant professorship of drawing, painting, "English literature, belles lettres and moral philosophy" at West Point from 1848 to 1849 (Hughes 1937).

FAMILY LIFE AND CIVIL WAR

Around 1844 Abert wed Jane Lenthall Stone of Washington, D.C., with whom he had a son, William Stone Abert. Jane Abert died in 1849. Published and archival sources lack further information on Abert's first wife. It appears that William Abert was somewhat estranged from his step-family, although he appears to have been close to his uncle Charles Abert, with whom he lived during the 1860s (Abert 1861–1862). Like Charles, William Abert became a powerful attorney in the District of Columbia and its Maryland suburbs (Abert Collection, UMR).

The widowed Abert wed Lucy Catherine Taylor in Newport, Kentucky, on 18 Jul 1851 (Veterans Administration Pension Records, UMR). Lucy came from the very wealthy and influential family of Gen. James Taylor and was connected to the equally powerful Preston family of Louisville (Abert Collection, Filson). Abert had three daughters with his second wife: Susan Barry, Ellen Matlock ("Nellie"), and Jane ("Jennie"). Jennie was the only one of Abert's daughters to marry. Susan and Nellie lived with their parents until the latters' deaths and then with each other (and Jennie following her husband's demise) (Mann n.d.). Abert had no grandchildren through his daughters, although William had several children.

Undoubtedly as a result of his family connections, Abert was transferred to Louisville shortly after his marriage to Lucy. Between 1851 and 1859, he supervised river improvements along the Ohio. His most notable achievement during this period was the construction of a navigational channel around rapids in the Ohio River at Marietta, Ohio (Mann n.d.). From 1856 to 1858 Abert took the field in Florida to serve as senior topographical engineer for army operations against the Seminole. This absence from Louisville and from his wife and children was a point of contention in Abert's personal life, as suggested by a

lengthy letter to his father-in-law in which he explained how his service in Florida was crucial to his career (Abert 1856). When hostilities ended, Abert returned to Louisville to serve as senior engineer on the Louisville and Portland Canal around the Ohio's falls (Abert Collection, Filson). Abert persisted in these duties until sectional tensions late in the Buchanan administration foretold coming civil conflict.

In preparation for the impending rebellion, Abert was sent to Europe from 1860 through spring 1861 to observe the latest developments in military science. He also used the opportunity to absorb European high culture, as evidenced by the many sketches of museum masterpieces that fill his sketchbook from the trip, which is now preserved in the Abert Collection at the Filson Historical Society. On 21 Jun 1861 Col. Hartmann Bache, who had replaced Abert's retired father as chief of the topographic corps, telegrammed Abert at Louisville ordering him to "Proceed to Hagerstown Maryland report to Gen. Patterson for duty" (orders preserved in Abert Collection, Filson). Abert served as chief topographer for Patterson and later for Patterson's successor, Maj. Gen. Nathaniel Banks, throughout federal operations in the Shenandoah Valley in 1861 and 1862.

Abert's field service in the Shenandoah was quite varied, as demonstrated in his unpublished military journal (Abert 1861) in the Filson Historical Society's Abert Collection. During the summer 1861 campaign Abert was most frequently occupied with general staff service and with mapmaking. When his time spent actually drafting maps is combined with his reconnaissance activities, over 40% of his time was devoted to these basic cartographic tasks, as indicated by an analysis of Abert's journal. During this period Banks' troops were frequently repositioned in the Valley in skittish response to localized Confederate aggression. It is therefore not surprising that Abert often had to guide troops or wagon trains to their destinations. Abert was on furlough for over 11% of his days of service that summer, frequently visiting his brother's Maryland farm outside Washington. Besides these dominant activities, he was also required to undertake various other duties, such as fording and bridging, fortifications engineering, camp selection and management, provost duties, and drilling troops. Abert even spent 1 day translating a brief French military textbook for Banks. In general, Abert's 1861 journal indicates that he spent most of his time providing Banks with the type of service one would expect from a senior career topographical officer on the staff of a predominately volunteer army. Pearson (2004) provided a detailed analysis of Abert's Shenandoah service in comparison to those of the other Union and Confederate topographical engineers in the theater.

During summer 1861 Abert produced for Banks a fine triangulation survey of the Shenandoah River. The carefully executed manuscript *Map of the Shenandoah River from Harper's Ferry to Port Republic* is housed at the National Archives as RG77:Z116. Figure 4 reproduces this 135 × 32 cm work. Although primarily intended to be a survey of the river itself, details such as tributaries, mills and dams, and place names facilitate the broader application of this data. The inset to Figure 4 demonstrates Abert's fine draftsmanship as well as the triangulation grid on which the map's features were registered. This map was most likely prepared as part of an unsuccessful Union scheme to transport supplies by steamboat on the Shenandoah.

Injuries plagued Abert's service after the Valley Campaign. He was severely wounded at Frederick, Maryland, in late 1862. After a period of convalescence, Abert assisted in the 1863 siege of Charleston, South Carolina, where he planned and supervised construction of the forts and battery emplacements that battered the city and its defenses from 4 to 6 miles away with tens of thousands of shells. This bombardment "rendered it uninhabitable to women and children, and converted the city into a mere soldiers' barracks, where . . . no quiet or comfort obtained" (Abert 1889). Abert also supervised construction of military works throughout coastal Virginia, Georgia, and the Carolinas through his role as chief engineer for all Union coastal operations. Abert's most notable achievement during this period was the design and construction of the batteries on the south side of the Savannah River that pounded the reportedly impregnable Fort Pulaski to submission in a single day (Abert 1889).

In early summer 1864 Abert was appointed

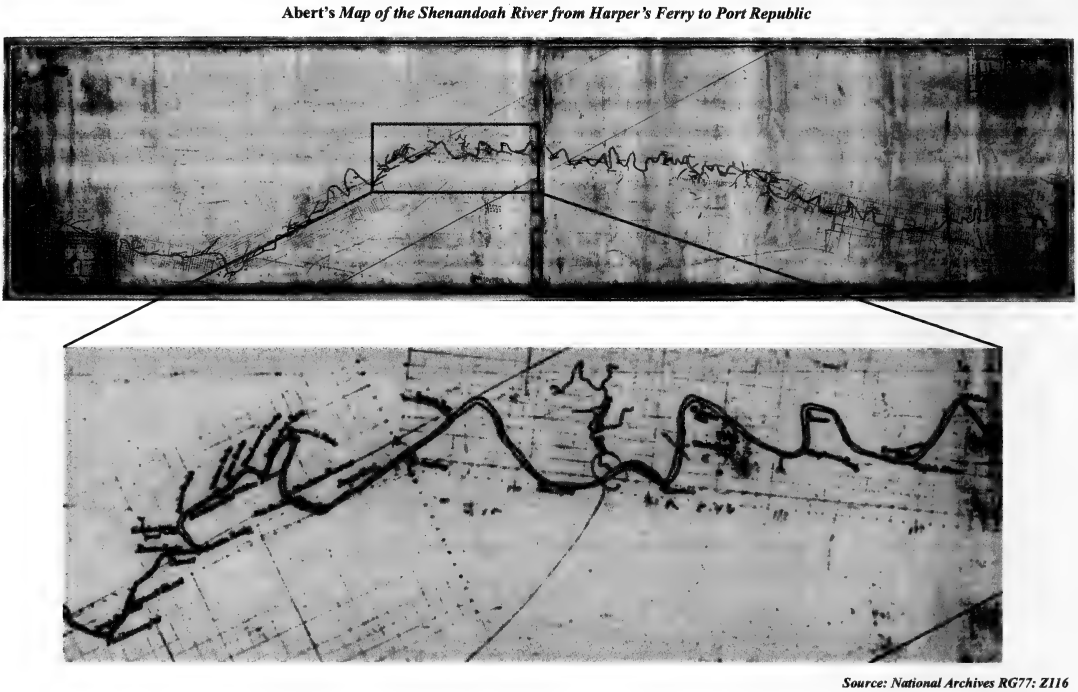

Figure 4. James W. Abert's map of the Shenandoah River from Harper's Ferry to Port Republic. Source: National Archives RG77:Z116.

chief engineer for the military department then being organized to supervise the lower Delta from Vicksburg following that stronghold's capitulation (Mann n.d.). Abert resigned from the army before he could relocate to Mississippi because of the sudden severe illness of his wife as well as the lingering complications from his wound earlier in the war.

POSTWAR SCHOLAR AND LAND DEVELOPER

Abert immediately entered business in Cincinnati and remained so engaged until being appointed one of three U.S. Examiners of Patents by President Ulysses S. Grant in 1868. He did not find the work rewarding. Instead of the intellectual stimulation he had expected from this position, Abert found only a tedium that, as he explained, "leaves so many of my talents and capabilities in a dormant state that I feel it cannot fill out the measure of my desires" (Abert 1871).

As a result of his desire for more stimulating employment, Abert secured a position as professor of English language and literature at the University of Missouri in Columbia, where he also taught courses in French, German, drawing, and painting. The University of Missouri's catalog for 1871–1872 states that Abert's "particular taste and artistic culture eminently qualify him to give instruction of the highest order to this important art [English literature] . . . indispensable . . . in all the applications of science to the pursuits of life" (Weinbach 1941, p. 20). Abert's decision to pursue a career in higher education was motivated by his enjoyment of occasional assignments over the years to teaching duties at West Point. I also suspect that his attraction to a career in academia was motivated by familiarity with his friend William G. Peck, who had resigned from the army in the early 1850s to pursue a long, successful career as a professor of mathematics at the University of Michigan.

After only a year in Columbia, Abert accepted a position as chair of civil engineering and drawing at the newly formed Missouri School of Mines (MSM) at Rolla. A photograph of Abert with others of the university's inaugural faculty is reproduced as Figure 5. Abert served MSM from 1872 until 1877, first as professor of civil engineering and drawing

James W. Abert and Missouri School of Mines First Faculty

Abert seated on left. ***Source: University of Missouri– Rolla Archives***

Figure 5. James W. Abert and other members of the first faculty of the Missouri School of Mines. Source: University of Missouri–Rolla archives.

and later as professor of applied mathematics and graphics. He left the institution in late October 1877 because of failing eyesight and impending university salary cuts (Mann n.d.).

Abert's family remained in Newport during his years in Missouri except for the 1876–1877 academic year, when three of his children (William, Nellie, and Jennie) attended MSM (Enrollment Records, Abert Collection, UMR). Abert constructed a large frame house in Rolla, which appears to have been visited only once by his wife (Abert Collection UMR). Abert, however, made frequent long trips to Kentucky during this period. Besides that which might be implied by their spatial separation, there is evidence that Abert and Lucy's marriage was troubled during this period. Sometime during the 1930s, MSM professor Claire V. Mann interviewed a colleague, Dr. Amaud N. Revold, who had been a student of Abert at MSM. Abert had frequently employed Revold "as 'driver' for week end parties . . . at Yancy Mills, on Little Piney River" (interview notes, Abert Collection, UMR), during which Abert would commonly escort the sister of his colleague Maj. George D. Emerson (who stands behind Abert in Figure 5). Frequently Abert and the female Emerson were physically indiscreet during her painting lessons on these excursions. Revold indicates that it was quite apparent that the two had some sort of relationship that was beyond casual.

After resigning from MSM, Abert returned to the home of his family in Newport, Kentucky. There he worked with his father-in-law to map, survey, and subdivide "the latter's extensive land holdings, which now comprise the town-sites of Newport and Fort Thomas, Kentucky" (Mann n.d.). Abert was very active in community affairs. He founded and was president of the local Henry Clay Society, as well

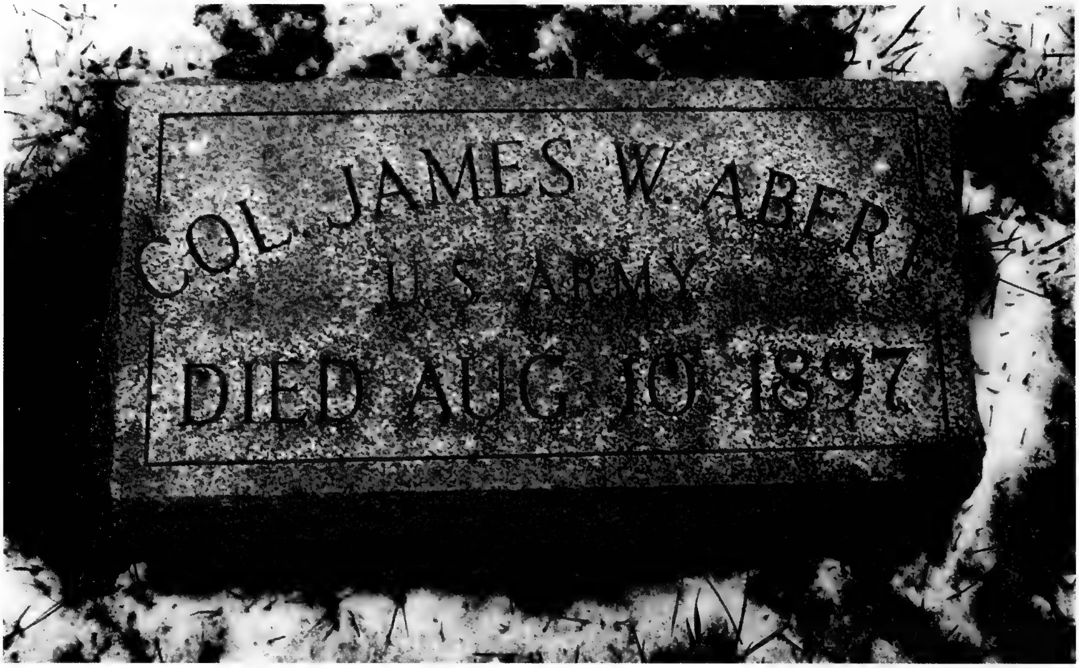

Figure 6. Headstone of James W. Abert, Evergreen Cemetery, Southgate, Kentucky, March 2005.

as the local Grand Army Post No. 178, which was named for him (Anonymous 1897a). Eight members were still alive in the 1930s when the post was closed and its membership folded into the local VFW (Dunlap 1938).

Following Abert's return to Kentucky from the Missouri School of Mines, he published six papers in *The Journal of the Cincinnati Society of Natural History.* His research was quite varied. Half of Abert's papers were ethnographic studies on native Americans, the Aztec calender stone, and Aztec astronomy. Besides providing evidence of Abert's reluctance to accept the Anasazi as an advanced native culture independent of those of the Valley of Mexico, Abert's work—both here and in his earlier reports to Congress—indicates a very progressive attitude toward indigenous North American societies. For example, Abert (1890) wrote that the "character [of pre-contact native Americans] must not be judged by the Indians of the present time, who have had their nobler sentiments destroyed during a period of four hundred years of cruelty, oppression, and injustice. The Indian of the present day is treacherous, ferocious and savage, filthy, miserable, drunken, broken-hearted and beggarly" (p. 89).

If one can overlook the Victorian paternalism in Abert's presentation, his comments indicate a conviction that, whatever degraded state he might ascribe to contemporary Indians, this cultural degradation is manifest only because of the ill worked against them by Europeans and Euro-Americans. Abert's writings of the 1840s (Abert 1846, 1847) indicate an appreciation for the right of native groups to exist as they always have, unmolested, even if that freedom required the reservation of territories large enough to sustain the herds of buffalo, elk, and other natural resources necessary for their subsistence along traditional lines. Throughout his life Abert believed that white Americans should curb their occupation of the landscape to accommodate native interests and prior claims to the land.

Abert's work on the Aztec calendar stone was connected to his interest in the Indians of the southwest because of his belief that the Anasazi culture was connected to that of the Aztec. Abert (1884a) wrote a detailed description of the use and construction of the ancient Mexican calendar device, as well as an analysis of Aztec astronomy and celestial timekeeping skills (Abert 1884a). This study relies heavily on Don Antonio de León y Gama's 1792 trea-

Figure 7. Headstone of Lucy Taylor Abert, wife of James W. Abert, Evergreen Cemetery, Southgate, Kentucky, March 2005.

tise on the subject, which Abert translated from the original Spanish (Abert 1885a). Abert's articles on these subjects indicate his long-standing interest in mathematics, mechanics, and earth systems processes.

This interest in the natural sciences is also evident in Abert's other scholarly publications from the last decade of his life. Cited in a previous section of this paper, Abert's (1889) article "Big Guns" explores the physics and mathematics of modern artillery in the context of technological advancement from the guns employed during the Civil War to the best field pieces and naval ordnance of the day. Abert's concise "On Color" (1884b) is focused primarily on the use of color wheels and the application of color theory to painting, interior design, and clothing. Throughout his discussion is a clear confidence that the principles of color theory can be systematically applied to solve all color issues in art and design. Abert's remaining scholarly paper from this period is a botanical study on the natural history of palms (1885b). Abert's (1893) last known publication is a biographical sketch about his brother Gen. William Stretch Abert.

Although he still dabbled in real estate development in northern Kentucky until the end of his life, Abert formally retired in 1887, when he applied for and received a military pension (Veterans Administration Records UMR). Abert died 10 Aug 1897 at Hillspoint, his estate on West Front Street in Newport, Kentucky, which was removed in the early 20th century to facilitate levee construction. His obituary in the *Kentucky Post* (Anonymous 1897b) attributes "the predisposing cause of [Abert's] death" to "poison recently contracted from handling weeds." Lucy Abert died at Hillspoint on 16 May 1916 in Newport, Kentucky. The gravestones of James and Lucy Abert in Evergreen Cemetery, Southgate, Kentucky, are shown in Figures 6 and 7, respectively.

Abert's daughters lived in the Highlands District of northern Kentucky until well into the 20th century. Susan Abert died on 15 Nov 1928 and Nellie Abert died on 6 Sep 1942. Both had lived together since 1912 at the former Shaw mansion at 26 Audubon Place in Fort Thomas (Daniels 2000; Mann n.d.). After her husband died, Jennie Abert Neff moved

Figure 8. Marker of the Abert family plot, Evergreen Cemetery, Southgate, Kentucky, March 2005.

to the house to live with her sisters. Jennie died on 12 Apr 1956. All three daughters are buried along with their parents in the Abert family plot shown in Figure 8.

CONCLUSION

Abert had a long career as explorer and scientist. During the 1840s Abert was an army topographical engineer exploring the frontiers of American settlement. He surveyed and mapped the future route of the Southern Pacific Railroad and the new U.S. territory of New Mexico. As part of these explorations Abert collected valuable geographic and biological data, which so impressed the scientists at the Smithsonian Institution that they named one family and seven species after him. His maps of New Mexico and parts of Arizona, Colorado, Oklahoma, and Texas were valuable documents which facilitated the administration and settlement of a large area of the American southwest during the mid-19th century. During the 1850s and 1860s, Abert supported the military and economic interests of the United States through his work on improvements to Ohio River navigation and through his service as topographical engineer during the Seminole and Civil Wars. Following the Confederacy's capitulation, Abert served as U.S. Examiner of Patents and then on the faculty of the University of Missouri at Columbia. He helped organize the Missouri School of Mines, where he served as the first Chair of the Civil Engineering Department. After leaving Missouri in 1877, Abert worked to develop Newport and Ft. Thomas, Kentucky out of his father-in-law's vast land holdings and contributed to the intellectual and cultural life of northern Kentucky through his various social and scholarly interests.

LITERATURE CITED

Abert Collection, Filson Historical Society manuscripts. Louisville, KY.

Abert Collection, UMR. University of Missouri–Rolla Archives.

Abert, C. 1861–1862. Unpublished manuscript diary. Library of Congress, Manuscript Division, Washington, D.C.

Abert, J. W. 1846. Lt. Abert's report of exploration of Comanche Country. 29th Congress, 1st Session. Senate Executive Document #438. GPO, Washington, D.C.

Abert, J. W. 1848. Report of Lieut. J. W. Abert of his examination of New Mexico in the years 1846–1847. 30th Congress, 1st Session. Senate Executive Document #23. GPO, Washington, D.C.

Abert, J. W. 21 Sep 1856. Unpublished letter to Col. James Taylor. James Taylor papers, Filson Historical Society manuscripts, Louisville, KY.

Abert, J. W. 1861 Military journal of Cpt. James W. Abert. Unpublished. Filson Historical Society manuscripts, Louisville, KY.

Abert, J. W. 1871. Unpublished letter to R. L. Todd. Abert Collection, University of Missouri–Rolla Archives.

Abert, J. W. 10 Mar 1876. Unpublished letter to J. S. Frost. Abert Collection, University of Missouri–Rolla Archives.

Abert, J. W. 1884a. The Aztec calendar stone. J. Cincinnati Soc. Nat. Hist. 7:181–193.

Abert, J. W. 1884b. On color. J. Cincinnati Soc. Nat. Hist. 7:167–173.

Abert, J. W. 1885a. The ancient Aztec, or Mexican, method of computing time. J. Cincinnati Soc. Nat. Hist. 8: 4–30.

Abert, J. W. 1885b. On palm trees. J. Cincinnati Soc. Nat. Hist. 8:35–46.

Abert, J. W. 1889. Big guns. J. Cincinnati Soc. Nat. Hist. 11:127–135.

Abert, J. W. 1890. The Indians of North America. J. Cincinnati Soc. Nat. Hist. 12:73–92.

Abert, J. W. 1893. General Wm. Stretch Abert: biographical notes. Kentucky Journal. 1 June.

Abert, J. W. 1966. Western America in 1846–1847: the original travel diary of Lieutenant J. W. Abert who mapped New Mexico for the United States army. John Galvin (ed). Howell, San Francisco, CA.

Abert, J. W. 1970. Through the country of the Comanche Indians in the fall of the year 1845: the journal of a U.S. army expedition led by Lieutenant James W. Abert of the topographical engineers. John Galvin (ed). Howell, San Francisco, CA.

Anonymous. 1897a. Abert obituary. Cincinnati Inquirer. 11 August.

Anonymous. 1897b. Col. Abert Dead. Kentucky Post. 11 August.

Carroll, H. B. 1941a. Gúadal P'a. Panhandle-Plains Historical Society, Canyon, TX.

Carroll, H. B. 1941b. Journal of Lt. J. W. Abert from Bent's Fort to St. Louis in 1845. Panhandle-Plains Hist. Rev. 24:9–113.

Daniels, B. M. 2000. Part I: early homesteads located in the district of the Highlands. Fort Thomas Living, January:16–18.

des Montaignes, F. 1972. The plains: being no less than a collection of veracious memoranda taken during the expedition of exploration in the year 1845, from the western settlements of Missouri to the Mexican border, and from Bent's Fort on the Arkansas to Fort Gibson, via South Fork of Canadian–North Mexico and north-western Texas. Nancy A. Mower and Don Russell (eds). Univ. Press, Norman, OK.

Dunlap, A. 1938. Unpublished 15 January letter to Claire V. Mann. Abert Collection, University of Missouri–Rolla Archives.

Galvin, J. 1966. Introduction. Western America in 1846–1847: the original travel diary of Lieutenant J. W. Abert who mapped New Mexico for the United States army. Howell, San Francisco, CA.

Galvin, J. 1970. Preface. Through the country of the Comanche Indians in the fall of the year 1845: the journal of a U.S. army expedition led by Lieutenant James W. Abert of the topographical engineers. Howell, San Francisco, CA.

Goetzmann, W. H. 1959. Army exploration in the American west, 1803–1863. Yale Univ. Press, New Haven, CT.

Hafen, L. 1973. Broken Hand: the life of Thomas Fitzpatrick, mountain man, guide, and Indian agent. Univ. Nebraska Press, Lincoln, NE.

Henry, J. 1869. Unpublished 2 April letter to Whom It May Concern. Abert Collection, University of Missouri–Rolla Archives.

Hughes, T. 1937. Unpublished letter to Claire V. Mann. Abert Collection, University of Missouri–Rolla Archives.

Mann, C. V. n.d. Unpublished biographical sketch of Col. James W. Abert. Abert Collection, University of Missouri–Rolla Archives.

Morris, J. M. 1999. Editor's introduction. Expedition to the southwest: an 1845 reconnaissance of Colorado, New Mexico, Texas and Oklahoma. Univ. Nebraska Press, Lincoln, NE.

Pearson, B. C. 2004. Civil War topographical engineering in the Shenandoah. Cartographic Perspectives 49 (Fall): 8–31.

Reis, J. 2000. Soldier-surveyor left mark on young nation. Kentucky Post. 11 December.

Ronda, J. P. 2003. Beyond Lewis and Clark: the army explores the west. Washington State Historical Society, Tacoma, WA. [Pages 48–52, 55.]

Traas, A. G. 1993. From the Golden Gate to Mexico City:

the U.S. army topographical engineers in the Mexican War, 1846–1848. U.S. Army, Washington, D.C.

Tyler, R. C., D. E. Barnett, and R. R. Barkley (eds). 1996. The new handbook of Texas. Vol. 1. Texas State Historical Association, Austin, TX.

Veterans Administration Pension Records, Abert Collection, University of Missouri–Rolla Archives.

Weinbach, M. P. 1941. Engineering at the University of Missouri, 1850–1940. Engineering Foundation, Columbia, MO.

J. Ky. Acad. Sci. 66(1):17–23. 2005.

Computational Investigations of the Octameric Enolase Enzyme

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ABSTRACT

Each step of glycolysis is characterized by a specific enzyme that acts to catalyze a given reaction. Unique amongst these reactions is the enolase-catalyzed transformation of 2-phosphoglycerate into phosphoenolpyruvate by dehydration. Studies have shown enolase to have a dimeric structure in all eukaryotes whereas the enzyme has been observed to possess an octameric structure in some extreme thermophile prokaryotes. Though a definitive determination of molecular architecture has not been made, anecdotal evidence seems to indicate that a tetrameric association of dimers is the most likely native form. This study has produced computational models for three mutation/deletion variants of the enzyme HL–S1 loop, which has been proposed as a contact point between the dimer subunits. Examination of these models with a dielectric constant of 40 has indicated a rapid deterioration of protein conformation; however, dielectric constants of 0 and 80 maintained overall structure. The study also showed that the deletion of residues 135–138 did not completely eliminate the alpha helix that was hypothesized to inhibit octameric structure.

INTRODUCTION

Enolase is found in every species that metabolizes glucose. The glycolytic pathway involves 10 steps to degrade glucose into pyruvate. In the ninth step of this process, enolase converts 2-phosphoglycerate to phosphoenolpryuvate (Figure 1). Two lysines and a glutamic acid residue help to catalyze this reaction. Two divalent magnesium ions also assist in this reaction (Klenchin et al. 2003; Reed et al. 1996).

Most enolases have subunit masses of about 45kDa. Eukaryotic enolases are dimer (Rider and Taylor 1974; Sawyer et al. 1986; Wolna et al. 1971). However, some, but not all, extreme thermophiles exist as an octamer (Schurig et al. 1995; Stellwagen et al. 1973). One exception is the hyperthermophilic bacterium *Thermotoga maritima,* which is a dimer (Schurig et al. 1995). It is unclear what metabolic advantage, if any, may exist for the octameric form.

To investigate enolase many groups have used various techniques including genetic trees (Canback et al. 2002; Oslancova and Janecek 2004), loop flexibility (Gunasekaran et al. 2003), high throughput analysis (Somiari et al. 2003), solvent mapping (Silberstein et al. 2003), and homology modeling (Copley and Bork 2000). This area of research will continue to grow as computational techniques are utilized with routine biochemical questions.

It has been proposed by Brown et al that four residues (135–138) of yeast enolase prohibit the formation of the octameric structure (Brown et al. 1998). These investigators proposed, from a manual arrangement of the dimers, that contact of these residues inhibits a tetramer of dimers (see Figure 6 in Brown et al. 1998). They suggested that the loop between helix L and strand 1 (HL–S1 loop) inhibits the formation of the octamer since that loop extends into the proposed interface region. They also suggested that the two glysines in thermophiles completes the elimination of this HL–S1 loop, allowing extended contact by Helix J. Based on their findings, we propose that deletion of the four residues in yeast enolase would not affect the structure. We further predict that the mutation, deletion, or both will not affect the overall stability of the structure. The entire HL–S1 loop will be eliminated only by mutation of residue A134 and deletion of residues 135–138. We further propose that the dielectric constant of 0 (in vacuum and often used for computational studies) or 80 (full aqueous solvent) will gen-

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Figure 1. Catalytic step of enolase in gylcolysis.

Figure 2. Sequence of crystal structure 4ENL modification area is highlighted. Residues 128–143 are shown. Residues highlighted in black show areas of modification. Sequence 1 residues 135–138 were deleted. Sequence 2 residues 135–138 were deleted and residue A134 was mutated to G. Sequence 3 residue A134 was mutated to G. Sequence 4 is the original sequence.

erate the best dynamics data and that 40 will result in loss of overall structure. The dynamics calculations at a dielectric of 40 will serve as a negative control to determine if loss of structure is possible under the calculation parameters, thereby allowing the determination of stability of the models over the dynamics simulations.

To test these hypotheses, the crystal structure 4ENL (Lebioda et al. 1989) was used as a starting point and the residues were either mutated or deleted or were both deleted and mutated. The modified structures were minimized and then underwent dynamics. Dynamics calculations were performed at dielectric constants of 0, 40, and 80 for all structures. The structures were then evaluated for stability both visually and through root mean squared deviation (RMSD) calculations.

MATERIALS AND METHODS

The protein structure of yeast enolase [protein databank 4ENL] was downloaded from the protein databank (Lebioda et al. 1989). Over 40 additional enolase amino acid sequences were downloaded from NCBI and aligned using the default settings in Molecular Operating Environment (MOE; 2003). Species varied from humans to extreme thermophiles and had homologies ranging from 35 to 96% (unpublished data). Chains two and three, containing solvent and other compounds, were deleted. The structure was then minimized with a conjugate gradient iteration limit of 100 and a truncated Newton RMS of 0.1 using the Amber94 force field in MOE (2003). Three additional structures were constructed to test the hypothesis that key residues are needed for contact between dimers of the proposed octameric structure. Residue A134 was mutated to G in the first model. A second model had four residues deleted: D135, L136, S137, and K138. The third structure had both the deletion of the above residues and the mutation A134G (Figure 2). The three new structures were minimized to the same gradient using the same parameters. Dynamics were preformed on all four files. Dynamics were preformed under NVT parameters for 1 fs time step with 30 ps of equilibration prior to the 100 ps data collection phase as in Wang et al. (2001).

During the equilibrium phase, a database of snapshot structures was created for all four dynamics calculations. The databases generated were then analyzed to determine if the structures were stable over the course of the dynamics. To that end, the structures were visually compared at the three dielectric constants. Also, the three new structures were compared to the original crystal structure. The structures were also compared quantitatively using Superimpose in the program MOE (Chemical Computing Group 2003) to determine RMSD of the alpha carbon backbone.

RESULTS

Visual Inspection

The dielectric constants of 0 and 80 maintained overall structure. The original structure was visually identical to the starting structure (Figure 3). The dielectric constant of 40

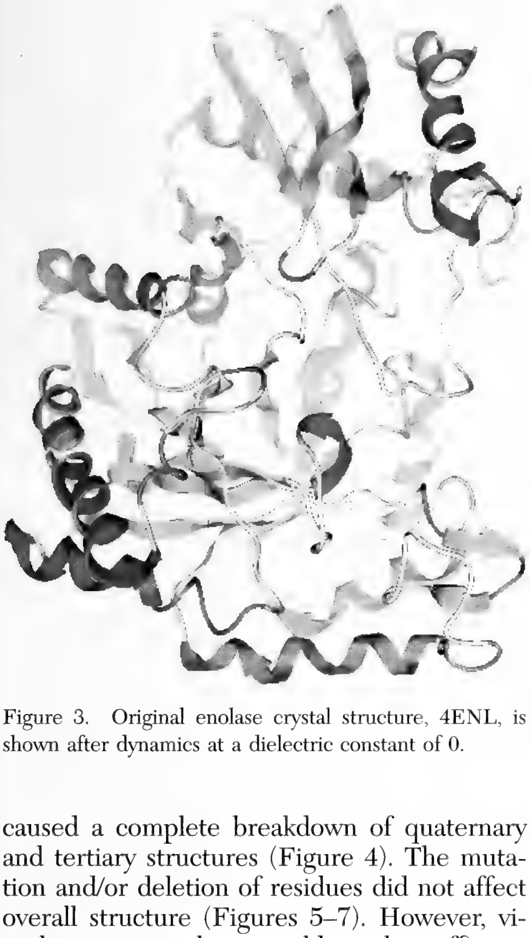

Figure 3. Original enolase crystal structure, 4ENL, is shown after dynamics at a dielectric constant of 0.

Figure 4. Original enolase crystal structure, 4ENL, is shown after dynamics at a dielectric constant of 40.

caused a complete breakdown of quaternary and tertiary structures (Figure 4). The mutation and/or deletion of residues did not affect overall structure (Figures 5–7). However, visual inspection alone would not be sufficient to distinguish between structures. The HL–S1 loop was not completely eliminated by the mutation of A134 and the deletion of residues 135–138 (Figure 8) as predicted in our hypothesis.

Root Mean Squared Deviation

Since the overall structure was lost at a dielectric constant of 40, that datum was not analyzed further. The remaining two structures from the dynamics at 0 and 80 were compared to the starting structure of the dynamics calculations. The RMSD values illustrate the similarity of the two dielectric constants. In all cases, the first entry of the equilibrium phase was compared to the 10th, 50th, or 100th entry of the dynamics simulation database. RMDS values varied from 0.16 to 0.26 Å^2 for the original protein. The values for the mutated, mutated and deleted, and deleted modifications vary from 0.29 to 0.88 Å^2. Clearly these values are higher than the original crystal structure but they are still very small deviations for dynamics simulations (Strahs and Weinstein 1997).

Figure 5. Mutation model, based on 4ENL crystal structure, is shown after dynamics at a dielectric constant of 0.

DISCUSSION

Yeast enolase was selected for this study for several reasons. The crystal structure is resolved to 2.25 Å. To date, no crystal structures have been solved for an octameric enolase. Homology models have been successfully developed in other systems with homology as low as 20%. (Fischer et al. 2001; Parrill, Baker et al. 2000; Parrill, Wang et al. 2000; Sardar et al. 2002) The homology for enolase is high enough to allow for this template selection, 35 to 96%; however, no homology model was developed. Deletion and/or mutation of the yeast crystal structure would allow the determination of the importance of the residues in question.

The original structure was visually inspected after the dynamics simulations at dielectric constants of 0, 40, and 80. The structure was intact at both 0 and 80 (Figure 3). However, the simulation at 40 suffered complete degradation of structure (Figure 4). The other structures suffered a similar fate. Structures for the three HL–S1 loop variants at a dielectric of 0 are shown in Figures 5–7, but structures for a dielectric of 40 are not shown. Structures are not shown for the dielectric of 80 since there is no visual difference between them.

The original hypothesis stated that the absence of residues 135–138 and the mutation of A134 to G are both important for the enolase enzyme to assemble into the octamer and that deletion of these residues would not decrease the stability of the model. It seems, however, that the dielectric constant is a more important variable. A more quantitative approach was needed to determine if differences existed between the three HL–S1 loop variants. By calculating the root mean squared deviation (RMSD) of the alpha carbon backbone of a protein we could achieve a measure of stability for the four models. According to Strahs, if a structure has an RMSD of 1.2 Å^2 or less the structure is stable and at equilibrium (Strahs and Weinstein 1997). All models were superimposed over the original minimized crystal structure. The RMSD values were calculated and the values indicated that the original structure was most stable (Table 1). The structures selected were the 1st, 50th, and 100th entries in the database. The system had reached equilibrium since the values between entry 50 and 100 were very similar in all cases. Each of the modified sequences had a RMSD value almost double that of the original structure, but the value was less than 1 Å^2 in all cases and often smaller than that. These values indicated that the proteins were all stable under the given conditions. However, the RMSDs indicated that the most stable structure was the original enzyme model. The second most stable model was the mutation only structure. The two deletion/mutation variant models, while having a higher RMSD value, still were determined to be stable. It is clear that the residues deleted did not cause a global loss of structure. Examination of the HL–S1 loop showed that the helix size was reduced but it was not entirely absent.

CONCLUSION

It is often necessary to use computational methods to obtain answers to difficult questions. These questions may not be answered by using traditional experimental methods but can provide a hypothesis for theoretical experiments. Those results can in turn provide data for traditional experiments. In this case, the use of computational methods allowed the investigator to examine the usefulness of various dielectric constants for the enolase enzyme and to examine a structural feature that was proposed to inhibit the assembly of the octameric enolase structure. We proposed that mutation of A134 to G and deletion of residues 135–138 would eliminate the HL–S1 loop. If this helix was completely eliminated, this would allow for the formation of an octameric structure. This study does not completely answer these questions but it does offer some answers. The residues 135–138 of yeast enolase are not required for the enzyme to maintain tertiary dimeric structure. Additionally, deletion of these residues and mutation of A134 to G does not completely remove the helix and therefore these residues may be required but not sufficient for formation of an octameric structure.

It can be concluded that the dielectric constant of the dynamics calculations was an important factor in the stability of the structures over the course of the simulation. Since a dielectric of 0 simulated the vacuum phase and 80 simulated the aqueous phase, it appeared that either of these two values was acceptable for the calculation. However, the dielectric of

Figure 6. Mutation and deletion model, based on 4ENL crystal structure, is shown after dynamics, dielectric constant of 0.

Figure 7. Deletion model, based on 4ENL crystal structure, is shown after dynamics at a dielectric constant of 0.

40, which simulated a lipid phase, caused a total loss of quaternary and tertiary structure. This result is not unexpected since enolase is an enzyme that exists in the aqueous environment of the cell. It did, however, serve as a control in that the parameters used allow for the models to explore geometric conformations that are distant from the starting structure. Therefore, the stability of the models at

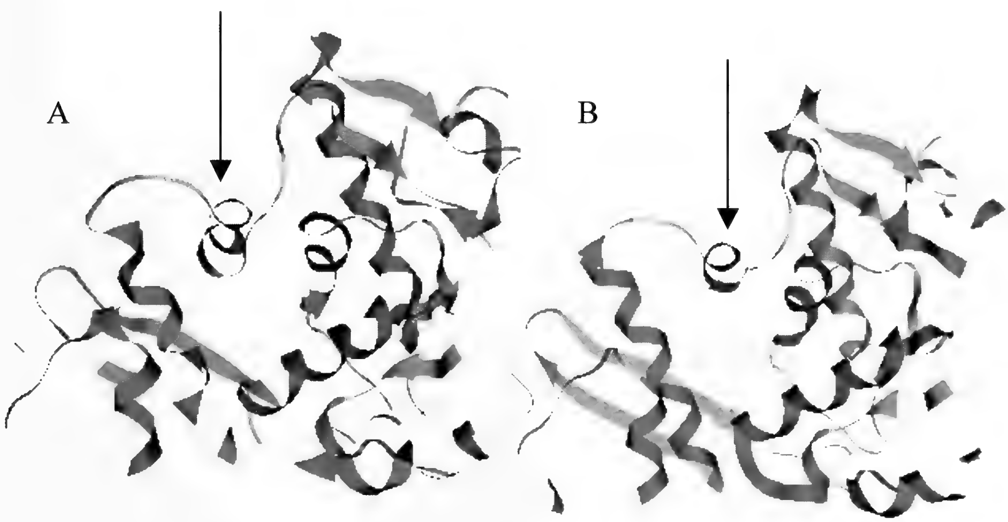

Figure 8. Close-up comparing 4ENL crystal structure and mutation and deletion model. Panel A. Area of original enzyme to highlight the HL–S1 loop after equilibration phase was completed. Panel B. Area of model with mutation of A134G and deletion of residues 135–138 after equilibration phase was completed to highlight the HL–S1 loop. Arrows indicate region of mutation and deletion.

Table 1. RSMD values for calculated using superimpose for dynamics snapshots.

	Enzyme structure			Loop		
Entries compared	1 vs. 10	1 vs. 50	1 vs. 100	1 vs. 10	1 vs. 50	1 vs. 100
Standard Protein Sequence						
Dielectric 0	0.163	0.213	0.255	0.0997	0.123	0.120
Dielectric 80	0.134	0.207	0.182	0.0828	0.106	0.107
Mutated Protein Sequence						
Dielectric 0	0.278	0.380	0.527	0.170	0.296	0.343
Dielectric 80	0.281	0.444	0.548	0.269	0.325	0.385
Deleted Protein Sequence						
Dielectric 0	0.453	0.739	0.876	0.427	0.280	0.438
Dielectric 80	0.290	0.461	0.563	0.174	0.268	0.323
Mutation/Deletion Protein Sequence						
Dielectric 0	0.485	0.731	0.747	0.259	0.345	0.551
Dielectric 80	0.287	0.510	0.657	0.227	0.216	0.291

dielectrics of 0 and 80 was not achieved by chance.

We determined that the most stable model was the original structure. This conclusion is not unexpected in that the structure was the crystal structure of yeast enolase, which is known to be a dimer. The second most stable structure was the mutation only model. This model was also clearly well below the required value for stability. The other two mutant/deletion variants were also well below the value of 1.2 Å^2 indicating very stable models. The deletion of residues 135–138 combined with the mutation of A134 to G was predicted to eliminate the small alpha helical loop (HL–S1). Figure 8 clearly shows that after the completed heating phase, the area still had approximately one helical turn. It was clearly reduced from three turns of the original structure, but the helix was not completely eliminated. This structure would still inhibit extensive interactions required for assembly of the octameric structure. We concluded that both deletion and mutation may be required but are not sufficient for this enzyme to assemble into an octamer. We predict, based on these computational studies, that if the corresponding biochemical experiments were performed, the yeast enolase would not adopt an octameric structure but would remain a dimer.

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LITERATURE CITED

Brown, C. K., P. L. Kuhlman, S. Mattingly, K. Slates, P. J. Calie, and W. W. Farrar. 1998. A model of the quaternary structure of enolases, based on structural and evolutionary analysis of the octameric enolase from *Bacillus subtilis.* J. Protein Chem. 17:855–866.

Canback, B., S. G. Andersson, and C. G. Kurland. 2002. The global phylogeny of glycolytic enzymes. Proc. Nat. Acad. Sci. U.S.A. 99:6097–6102.

Copley, R. R., and P. Bork. 2000. Homology among (betaalpha)(8) barrels: implications for the evolution of metabolic pathways. J. Molecular Biol. 303:627–641.

Fischer, D. J., N. Nusser, T. Virag, K. Yokoyama, D. A. Wang, D. L. Baker, D. Bautista, A. L. Parrill, and G. Tigyi. 2001. Short-chain phosphatidates are subtype-selective antagonists of lysophosphatidic acid receptors. Molecular Pharmacol. 60:776–784.

Gunasekaran, K., B. Ma, and R. Nussinov. 2003. Triggering loops and enzyme function: identification of loops that trigger and modulate movements. J. Molecular Biol. 332:143–159.

Klenchin, V. A., E. A. Taylor Ringia, J. A. Gerlt, and I. Rayment. 2003. Evolution of enzymatic activity in the enolase superfamily: structural and mutagenic studies of the mechanism of the reaction catalyzed by o-succinylbenzoate synthase from *Escherichia coli.* Biochemistry 42:14427–14433.

Lebioda, L., B. Stec, and J. M. Brewer. 1989. The structure of yeast enolase at 2.25-A resolution. An 8-fold beta + alpha-barrel with a novel beta beta alpha alpha (beta alpha)6 topology. J. Biol. Chem. 264:3685–3693.

[MOE] Molecular Operating Environment. 2003. The Chemical Computing Group. Montreal, Canada.

Oslancova, A., and S. Janecek. 2004. Evolutionary relatedness between glycolytic enzymes most frequently occurring in genomes. Folia Microbiol. 49:247–258.

Parrill, A. L., D. L. Baker, D. A. Wang, D. J. Fischer, D. L. Bautista, J. Van Brocklyn, S. Spiegel, and G. Tigyi. 2000. Structural features of EDG1 receptor-ligand complexes revealed by computational modeling and mutagenesis. Ann. New York Acad. Sci. 905:330–339.

Parrill, A. L., D. A. Wang, D. L. Bautista, J. R. Van Brocklyn, Z. Lorincz, D. J. Fischer, D. L. Baker, K. Liliom, S. Spiegel, and G. Tigyi. 2000. Identification of Edg1 receptor residues that recognize sphingosine 1-phosphate. J. Biol. Chem. 275:39379–39384.

Reed, G. H., R. R. Poyner, T. M. Larsen, J. E. Wedekind, and I. Rayment. 1996. Structural and mechanistic studies of enolase. Curr. Opinion in Structural Biol. 6:736–743.

Rider, C. C., and C. B. Taylor. 1974. Enolase isoenzymes in rat tissues. Electrophoretic, chromatographic, immunological and kinetic properties. Biochim. Biophys. Acta 365:285–300.

Sardar, V. M., D. L. Bautista, D. J. Fischer, K. Yokoyama, N. Nusser, T. Virag, D. A. Wang, D. L. Baker, G. Tigyi, and A. L. Parrill. 2002. Molecular basis for lysophosphatidic acid receptor antagonist selectivity. Biochim. Biophys. Acta 1582:309–317.

Sawyer, L., L. A. Fothergill-Gilmore, and G. A. Russell. 1986. The predicted secondary structure of enolase. Biochem. J. 236:127–130.

Schurig, H., K. Rutkat, R. Rachel, and R. Jaenicke. 1995. Octameric enolase from the hyperthermophilic bacterium *Thermotoga maritima*: purification, characterization, and image processing. Protein Sci. 4:228–236.

Silberstein, M., S. Dennis, L. Brown, T. Kortvelyesi, K. Clodfelter, and S. Vajda. 2003. Identification of substrate binding sites in enzymes by computational solvent mapping. J. Molecular Biol. 332:1095–1113.

Somiari, R. I., A. Sullivan, S. Russell, S. Somiari, H. Hu, R. Jordan, A. George, R. Katenhusen, A. Buchowiecka, C. Arciero, H. Brzeski, J. Hooke, and C. Shriver. 2003. High-throughput proteomic analysis of human infiltrating ductal carcinoma of the breast. Proteomics 3:1863–1873.

Stellwagen, E., M. M. Cronlund, and L. D. Barnes. 1973. A thermostable enolase from the extreme thermophile *Thermus aquaticus* YT-1. Biochemistry 12:1552–1559.

Strahs, D., and H. Weinstein. 1997. Comparative modeling and molecular dynamics studies of the delta, kappa and mu opioid receptors. Protein Engin. 10:1019–1038.

Wang, D. A., Z. Lorincz, D. L. Bautista, K. Liliom, G. Tigyi, and A. L. Parrill. 2001. A single amino acid determines lysophospholipid specificity of the S1P1 (EDG1) and LPA1 (EDG2) phospholipid growth factor receptors. J. Biol. Chem. 276:49213–49220.

Wolna, E., M. Wolny, and T. Baranowski. 1971. The properties of crystalline phosphopyruvate hydratase from swine muscle. Acta Biochim. Polon. 18:87–92.

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Vascular Flora from Five Plant Habitats of an Abandoned Limestone Quarry in Clark County, Kentucky

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ABSTRACT

The vascular flora of an abandoned limestone quarry adjacent to the Kentucky River in Clark County, Kentucky, was studied from 1993 through 1999. A total of 260 species in 181 genera from 64 families were found in five diverse habitats. Fifty-seven (21.9%) were Clark County distributional records. Seventy-three (28.1%) were exotic species; 22 of these are Kentucky naturalized invasive pest plants. Taxa are classified into Equisetophyta (2), Polypodiophyta (2), Pinophyta (1), and Magnoliophyta (255). Largest families were Asteraceae (43), Poaceae (30), Fabaceae (15), Cyperaceae (13), and Rosaceae (10). Two state-listed species, *Liparis loeselii* and *Spiranthes lucida,* were present in the quarry.

INTRODUCTION

A high plant species richness has been found from surveys of limestone quarries and coal surface-mined areas in eastern United States. These drastically disturbed areas have developed unique habitats for colonization of vascular plants not available on unquarried or unmined land. Ross (1970) found 271 species in a survey of the vascular flora of a limestone quarry on the Marblehead Peninsula, Ottawa County, Ohio. Reinking (1979) reported 276 vascular plant species in a floristic analysis of two abandoned limestone quarries on Kelleys Island, Erie County, Ohio. In floristic surveys of five coal surface-mined areas from 2.5 to 14.3 ha in eastern Kentucky the species numbers were 272 (Thompson and Wade 1991), 299 (Wade and Thompson 2002), 312 (Rafaill and Thompson 2002), 350 (Thompson et al. 1984), to 360 (Thompson et al. 1996). These numbers are significant when 272 species on such a small mined area with a history of disturbance supports 10.5% of the Kentucky vascular flora based on Jones (2005).

The diverse habitats created from coal surface-mining not only allow for a high species richness but serve as specialized habitats or "refugia" for rare species not found in contiguous environs. One or more Kentucky state-listed species (KSNPC 2000) have been found at each of the five previously listed surface-mined areas (Rafaill and Thompson 2002; Wade and Thompson 1993). In European vegetation studies, several rare and protected species have become established in limestone quarry habitats in Hungary (Balint and Terpo 1986) and in Great Britain (Hodgson 1982; Jefferson 1984; Usher 1979).

Fewer plant surveys have been made on limestone quarries than on coal surface-mined lands in the eastern United States. We studied the flora of a 0.65 ha abandoned quarry in Clark County, central Kentucky, from 1993 to 1999 to gather baseline information. Our objectives were (1) to document the vascular plants with representative vouchers, (2) to describe the plant habitats with plant associates, and (3) to compile an annotated list of species with plant origin (exotic or native), plant habitat(s), and relative abundance value for each species. Our data are presented in the Appendix.

THE STUDY SITE

The 0.65 ha (6500 m^2) abandoned quarry lies at latitude 37°55′00″ N, and longitude

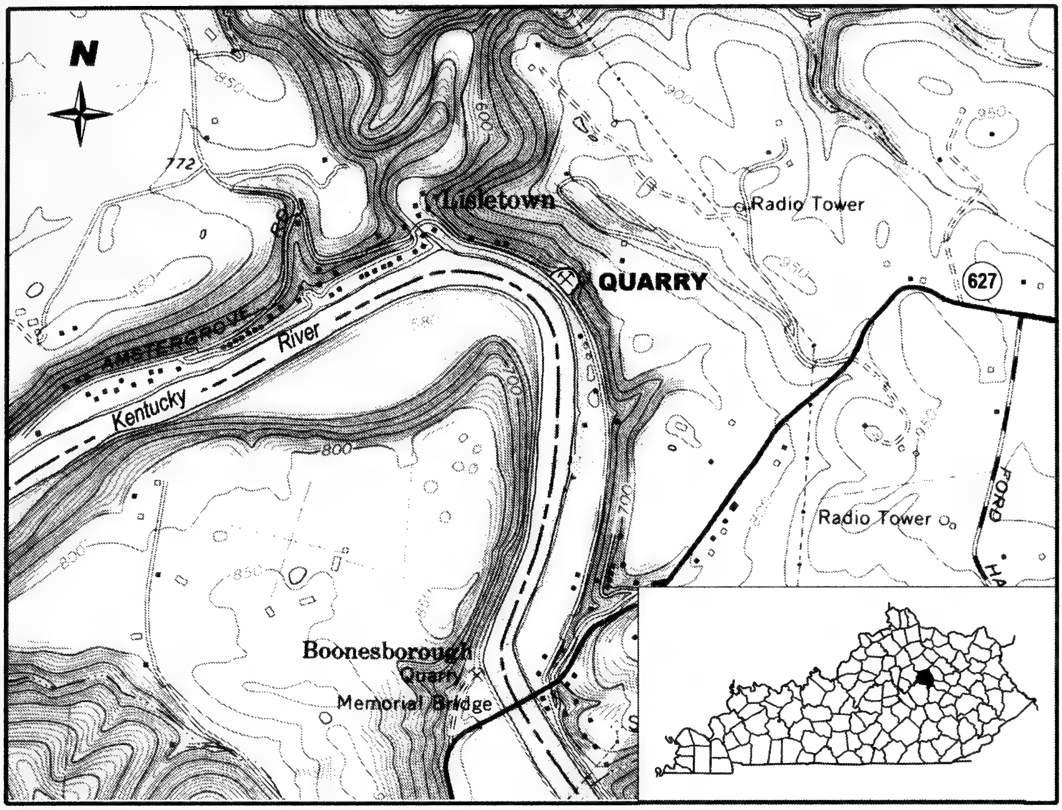

Figure 1. Location of abandoned limestone quarry along Kentucky River near Lisletown, Clark County, Kentucky. Adapted from Ford Quadrangle, 7.5 minute topographic series, 1965. U.S. Geological Survey, Washington, DC.

84°16′02″ W adjacent to the Kentucky River in Clark County. It is located 1.4 km west on Kentucky State Highway 418 (KY 418) near Lisletown northwest from the Ewart W. Johnson Memorial Bridge of Kentucky State Highway 627 (Figure 1). The southwest-trending rectangular quarry is bordered by vertical limestone highwalls on three sides and by the asphalt-paved KY 418 (Old Athens-Boonesboro Road) on the front side.

The quarry was first active when limestone aggregate was quarried for construction of the Memorial Bridge from 1928 to 1930. The quarry then became inactive until 1935. From 1935 to 1960, the quarry provided aggregate and agriculture lime, and an on-site asphalt paving company was operated. In 1960, the quarry was abandoned, and the asphalt machinery and a dynamite shed were left on the site. Plant colonization (dispersal and establishment), progressive plant succession, and soil development have occurred for over 44 years in the inactive quarry.

The quarry lies in the Inner Bluegrass Subsection of the Bluegrass Section of the Interior Low Plateau in the Eastern Broadleaf Forest (Continental) Province (Keys et al. 1995), or at the very edge of the Inner Bluegrass of the Interior Plateau (Wharton and Barbour 1991; Woods et al. 2002).

The oldest Middle Ordovician System rocks are Camp Nelson, Oregon, and Tyrone Limestones, of the High Bridge Group, which outcrop only along the Kentucky River (Cressman and Noger 1976). These are the three exposed limestone and dolomite formations making up the 45.0 m southwest-trending highwall. Camp Nelson Limestone, the light brownish gray dolomitic limestone quarried underground, forms the quarry floor upward from 173 to 201 m. The Oregon Formation, a brownish orange to brownish yellow calcare-

ous dolomite, extends from 201 to 213 m, and joins the Tyrone Limestone, a light brownish gray limestone from 213 to 219 m at the top of the highwall (Black 1968).

Along the Kentucky River in Clark County, the McAfee-Salvisa-Ashwood Association predominates on uplands. These soils are only slightly acid, shallow to deep, droughty, clayey soils on the sloping and steep rolling terrain underlaid by High Bridge limestones. On the steep side slopes and ridgecrest where limestone outcrops are the neutral to alkaline Rock Land soils (Preston et al. 1964). Rock Land is the predominant soil adjacent to the quarry and adjoins the Ashwood very rocky silty clay soil series of the uplands.

In central Kentucky, the climate is temperate humid continental characterized by cool winters and warm summers with precipitation spread throughout the year (Trewartha and Horn 1980). Climatic data, 1977–2000, are from the Eastern Kentucky University weather station, Richmond, in Madison County, 19.3 km north of the abandoned quarry. Mean annual temperature is 12.7°C with the mean lowest temperature in January, −0.2°C, and the mean highest temperature in July, 24.4°C. The mean annual precipitation is 117.8 cm with the lowest precipitation, 7.3 cm, in October and the highest precipitation, 11.8 cm, in May (Kentucky Climate Center 2001). The mean growing season is 196 days with the median first fall occurrence of frost on October 24 and the last spring occurrence on April 11 (Kentucky Climate Center 2001).

Forest vegetation in the vicinity of the study site is classified as Western Mesophytic Forest Region by Braun (1950). More precisely, in the Kentucky River Palisades of Madison County, across the Kentucky River from Clark County, Martin et al. (1979) found forested slopes to be representative of the *Acer saccharum-Fraxinus* spp.-*Quercus* spp. community. On floodplains, an *Acer negundo-A. saccharinum-Platanus occidentalis* community exists, while on exposed upland limestone outcrops, a *Juniperus virginiana* community predominates. Campbell et al. (1995) classified mature forests on subxeric areas of Raven Run Nature Sanctuary, in the Kentucky River Palisades of adjoining Fayette County, as *Quercus-Fraxinus-Juniperus* forest and a mixture of *Quercus-Fraxinus-Acer saccharum* forest.

At the abandoned quarry site, a reconnaissance of the subxeric upper slope above the southwest-trending highwall revealed that *Juniperus virginiana* and *Quercus muhlenbergii* are the codominant canopy species. Other important overstory trees are *Acer saccharum, Celtis occidentalis, Cercis canadensis, Fraxinus americana, F. quadrangulata, Prunus serotina, Quercus shumardii, Robinia pseudoacacia,* and *Ulmus rubra.* Important shrubs and vines are *Lonicera maackii, Parthenocissus quinquefolia, Rhus aromatica, Toxicodendron radicans,* and *Viburnum rufidulum.* On the more mesic side slopes, *Acer saccharum* is the dominant canopy tree. Important overstory trees are *Aesculus glabra, Cercis canadensis, Fraxinus americana, Ostyra virginiana, Quercus muhlenbergii, Q. shumardii,* and *Ulmus rubra.* Important shrubs and vines are *Bignonia capreolata, Cornus drummondii, Lonicera japonica, L. maackii, Menispermum canadense, Staphylea trifolia, Toxicodendron radicans,* and *Vitis vulpina.*

METHODS

Vascular plant specimens were collected during the growing seasons of 1993–1999 and were deposited in the Berea College Herbarium (BEREA). Duplicates have been deposited at Eastern Kentucky University (EKY), Richmond. Identification and nomenclature were based on Gleason and Cronquist (1991).

In the Appendix an annotated list of taxa is alphabetically arranged by family and species. Origin of taxa (exotic or native), invasive exotic pest species, habitats, relative abundance, and a representative collection number are listed for each taxon. Plant habitats were determined through field survey work with characteristic species in the canopy, subcanopy, shrub, and herb layers, physical site features (soils, topography, moisture, insolation), and tree sampling data as major parameters. Sampling for relative density (species composition) of trees was conducted by counting seedlings (<1.0 m tall) and saplings (<0.5 dm dbh). Decimeter (dm) size-classes for trees (>0.5 dm) was determined with Haglof Mantax Aluminum Calipers®.

RESULTS AND DISCUSSION

Taxonomic Summary

The vascular flora consists of 260 species in 181 genera from 64 families (Appendix). Sev-

enty-three (28.1%) were exotics of which 22 are Kentucky naturalized invasive exotic pest plants. Fifty-seven (21.9%) are Clark County distributional records. Plants are classified into 2 Equisetophyta, 2 Polypodiophyta, 1 Pinophyta, and 255 Magnoliophyta (200 Magnoliopsida and 55 Liliopsida). The seven largest families, Asteraceae (43), Poaceae (30), Fabaceae (15), Cyperaceae (13), Rosaceae (10), and Apiaceae and Scrophulariaceae (9 each), comprise 49.6% of the total plant species. Largest genera are *Carex* (6), *Aster* (5), and *Asclepias, Eupatorium,* and *Euphorbia* (4 each).

State-listed Rare Species

Liparis loeselii (Thompson 94-701) and *Spiranthes lucida (Thompson 94-426)* were documented for Clark County in the abandoned quarry (Abbott et al. 2004). These two state-listed orchids are classified as "Threatened" by the KSNPC (2000). *Liparis loeselii* was initially reported for Kentucky in Harlan County by MacGregor (1983) and Bell County by Thompson and MacGregor (1986).

Invasive Species

Kentucky has 55 species listed by the Kentucky Exotic Pest Plant Council in the "Severe Threat" and "Significant Threat" categories (KY-EPPC 2001). Of the 22 invasive exotics from these two categories in the quarry, the northeast Asian shrub *Lonicera maackii* is spreading the most rapidly. In 1993, this naturalized shrub was rare with its seed source as seed rain from the upland environs. Currently, it has spread into all habitats except the permanent pond and will continue to aggressively migrate. Campbell et al. (1995) reported *Lonicera maackii* as widespread and abundant throughout Raven Run Nature Sanctuary in the Kentucky River Palisades of Fayette County. Other exotics pests exhibiting an impact upon native species in the quarry are *Coronilla varia, Festuca arundinacea, Lespedeza cuneata, Lonicera japonica, Microstegium vimineum,* and *Rosa multiflora.*

Plant Habitats

Five plant habitats delineated in the quarry are the Xeric Vertical Highwall, Mesic Highwall Talus Slope, Permanent Pool and Drainage Ditch, Subxeric Quarry Floor and Haul Road, and Elevated Spoil Pile.

Xeric vertical highwall. The 46.5 m high vertical highwall at the back of the quarry has two sloping vertical sides down to the level front at KY 418. Most vines are rooted in the talus slope habitat and are climbing upward, but several vines and herbs are scattered in cracks, crevices, and ledges. Characteristic woody vines are *Bignonia capreolata, Campsis radicans, Parthenocissus quinquefolia, Toxicodendron radicans,* and *Vitis vulpina. Juniperus virginiana* and *Lonicera maackii* are found growing on ledge surfaces. Some herbs embedded in the highwall are *Ambrosia artemisiifolia, Aquilegia canadensis, Arabis laevigata, Asplenium platyneuron, Aster pilosus, Dactylis glomerata, Festuca arundinacea, Hedeoma pulegioides, Melilotus alba,* and *Poa compressa.*

Mesic highwall talus slope. This 1100 m^2 habitat is composed of weathered rock and soil 4–8 m high at the base of the vertical highwall on three sides of the quarry. The talus slope is shaded at some period during the day and several seeps provide moisture. The talus slope is bordered by the permanent pool and its ditch.

Twenty-four tree species are represented in the talus slope habitat. *Acer saccharum* and *Cornus drummondii* account for 46.0 percent relative density. Other important trees and tree saplings in order of relative densitiy are *Acer negundo, Aesculus glabra, Ulmus rubra, Fraxinus americana, Cercis canadensis,* and *Platanus occidentalis.* Indicator vines are primarily those species of the vertical highwall habitat. Other vines and shrubs include *Hydrangea arborescens, Rubus occidentalis, Sambucus canadensis,* and *Smilax rotundifolia.*

Characteristic herbaceous species include *Aster shortii, Carex blanda, C. grisea, Elymus virginicus, Eupatorium rugosum, Festuca elatior, Impatiens capensis, I. pallida, Microstegium vimineum, Osmorhiza longistylis, Pilea pumila, Polymnia canadensis, Sanicula gregaria, Saponaria officinalis,* and *Sedum pulchellum.*

Permanent pool and drainage ditch. A 2400 m^2 ponded habitat was created by water pooling from underground quarrying seepage and drainage. This pool is connected by a narrow drainage ditch to a 40.0 dm concrete

opening under KY 418 into the Kentucky River. Ten tree species were found. *Salix nigra* and *S. exigua* comprised 64.4 percent of the relative density. Other important trees in relative density were *Acer negundo, A. saccharinum, Platanus occidentalis,* and *Fraxinus pennsylvanica.* This habitat exhibits typical pond hydrosere succession. The ponded water surface is covered by scattered mats of *Lemna minor.* The most important species of the emergent zone of the pond and drainway border is *Typha latifolia.* Other characteristic emergent species are *Alisma subcordatum, Eleocharis obtusa, Juncus acuminatus, J. effusus* var. *solutus, J. tenuis, Ludwigia alternifolia, Mentha ×piperita, Sagittaria australis,* and *Scirpus cyperinus.*

A narrow wetland meadow transitional to the emergent zone of the permanent pond and drainway has considerable species overlap with the emergent zone. In addition to those of the emergent zone, characteristic species include *Apocynum cannabinum, Asclepias incarnata, Bidens comosa, Carex cristatella, C. frankii, C. lurida, C. vulpinoidea, Epilobium coloratum, Galium tinctorium, Glyceria striata, Impatiens capensis, Leersia oryzoides, Lobelia siphilitica, Lycopus americanus, Mimulus ringens, Pilea pumila, Prunella vulgaris,* and *Scirpus atrovirens. Liparis loeselii*—a colony of 14 plants—was present on vegetation mats within the *Typha latifolia* border. Three plants of *Spiranthes lucida* were found on the edge of the pool border and highwall talus habitat.

Subxeric quarry floor and haul road. This 3000 m^2 habitat was initially composed of two portions. A 4.0 m high elevated upper portion encompasses an impacted limestone aggregated area with a haul road for limestone materials that joins the southwestern boundary of KY 418. A lower quarry portion abutted the permanent pool and drainage ditch habitat and has the old asphalt machinery and dynamite storage shed.

Nineteen tree species are found in this habitat with *Juniperus virginiana* dominant with 63.0 percent of the relative density. Other trees in order of importance are *Robinia pseudoacacia, Platanus occidentalis, Ulmus rubra, Prunus mahaleb, Cercis canadensis,* and *Fraxinus americana.* Characteristic shrubs and vines of old-field succession are *Celastrus scandens, Lonicera japonica, L. maackii, Parthenocissus quinquefolia, Rhus aromatica, R. glabra, Rosa multiflora, Rubus occidentalis, Symphoricarpos orbiculatus, Toxicodendron radicans, Viburnum rufidulum,* and *Vitis vulpina.*

The subxeric quarry floor and haul road have the highest species richness of any habitat in the quarry. Early to mid-seral stages of progressive secondary succession have developed in this disturbed habitat. Many native and exotic biennial and perennial herbs are present throughout the growing season. Characteristic herbs include *Andropogon virginicus, Aster pilosus, A. novae-angliae, Chrysanthemum leucanthemum, Cichorium intybus, Coronilla varia, Erigeron annuus, Eupatorium hyssopifolium, Festuca elatior, Kuhnia eupatorioides, Lespedeza cuneata, L. stipulacea, Melilotus alba, Poa compressa, Solidago canadensis, S. nemoralis,* and *Tridens flavus.*

Elevated spoil pile. In October 1995, the lower portion of the subxeric quarry floor habitat was bulldozed and the disused asphalt equipment and dynamite shed were removed. Bulldozing created a 0.5–1.0 m elevated spoil pile area of 800 m^2 as a new habitat for secondary plant succession. The limestone substrate consists of aggregated gravel intermixed with subxeric quarry floor soils and its seed bank.

After this severe disturbance, rapid plant succession occurred with propagules from seed bank sources in the quarry habitats as well as from seed rain of the surrounding environs. In 1995–1997, characteristic pioneer weedy species were *Bromus japonicus, Cardamine hirsuta, Carduus nutans, Cerastium vulgatum, Daucus carota, Dipsacus sylvestris, Erigeron annuus, Medicago lupulina, Melilotus alba, Microstegium vimineum, Oenothera biennis, Oxalis stricta, Poa annua, Stellaria media, Trifolium campestre, Verbascum thapsus,* and *Veronica arvensis.*

Pioneer succession was quickly followed with perennial herbs and woody species invading the elevated spoil pile in 1997–1999. Perennial herbs were mainly those species of the subxeric quarry floor and haul road habitat. Other perennial herbs found were *Aster lateriflorus, Cirsium discolor, Elymus virginicus, Eupatorium fistulosum, E. rugosum, Lobelia*

siphilitica, Taraxacum officinale, and *Tussilago farfara.*

At present in 2004, woody species are becoming established and will continue colonizing the elevated spoil pile. Tree seedlings and saplings include *Acer negundo, A. saccharinum, Juniperus virginiana, Morus alba, Platanus occidentalis, Robinia pseudoacacia, Salix nigra,* and *Ulmus rubra.* The major shrub invaders are *Cornus drummondii, Lonicera maackii, Rosa multiflora,* and *Rubus occidentalis.*

CONCLUSIONS

The 0.65 ha abandoned limestone quarry at Clark County has a high species richness with 260 species. This species number constitutes 10 percent of the vascular flora for Kentucky. A rich vascular flora has colonized five diverse quarry habitats through 44 years of progressive secondary succession and soil development within close proximity to forest and ruderal environs. Colonization has involved dispersal of propagules from these environs through forces of wind, water, and gravity, and from the quarry seed bank and the establishment of plants. Several species are restricted to the quarry and not found in the rest of Clark County because of the unique quarry habitats available. Fifty-seven new Clark County plant species were documented in the quarry based on the Clark County flora survey completed in 1954.

In the six years of this study, 1993–1999, several species have colonized the quarry habitats while some have become extirpated because of plant succession and environmental disturbances. Recent species fluctuations have been especially observable after bulldozing activities created a new habitat for plant colonization in October 1995. Exotic plants comprise a significant percentage of the total flora in the quarry and have made an impact upon the native vegetation.

As in the case of revegetated Kentucky coal surface-mined areas with rare and protected species, this abandoned limestone quarry in Clark County has become a "refugium" for certain Kentucky state-listed wetland species to grow and persist in the Inner Bluegrass Ecoregion of the Interior Plateau.

LITERATURE CITED

Abbott, J. R., R. L. Thompson, and R. A. Gelis. 2004. Noteworthy vascular plants of Kentucky: a state record, range extensions, and various species of interest. J. Kentucky Acad. Sci. 65:94–103.

Balint, K. E., and A. Terpo. 1986. Immigration of plant species into abandoned vineyards and stone quarries. Acta Agron. Hung. 35:315–326.

Beal, E. O., and J. W. Thieret. 1986. Aquatic and wetland plants of Kentucky. Kentucky State Nature Preserves Comm. Sci. Techn. Ser. 5.

Beckett, M. R. 1956. The flora of Clark County, Kentucky, in relation to geologic regions. M.A. Thesis. Univ. Kentucky, Lexington, KY.

Black, D. F. B. 1968. Geologic map of the Ford Quadrangle, central Kentucky. Map GQ-764. U.S. Geological Survey, Department of the Interior (map scale 1: 24,000), Washington, DC.

Braun, E. L. 1943. An annotated catalog of spermatophytes of Kentucky. John S. Swift, Cincinnati, OH.

Braun, E. L. 1950. Deciduous forests of eastern North America. Hafner Press Publishing Co., New York, NY.

Campbell, J., D. G. Ruch, and W. Meijer. 1995. Flora and vegetation of Raven Run Nature Sanctuary, Fayette County, Kentucky. Proc. Indiana Acad. Sci. 104:139–184.

Cressman, E. R., and M. C. Noger. 1976. Tidal-flat carbonate environments in the High Bridge Group (Middle Ordovician) of central Kentucky. Kentucky Geol. Surv., Series X, Frankfort, KY.

Gleason, H. A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada, 2nd ed. New York Botanical Garden, Bronx, NY.

Hodgson, J. G. 1982. The botanical interest and value of quarries. Pages 3–11 in B. N. K. Davis (ed). Ecology of quarries: the importance of natural vegetation. Institute of Terrestrial Ecology, Cambridge, England.

Jefferson, R. G. 1984. The vascular flora of disused chalk pits and quarries in the Yorkshire Wolds. Naturalist 109: 19–22.

Jones, R. L. 2005. Plant life of Kentucky—an illustrated guide to the vascular flora. Univ. Press Kentucky, Lexington, KY.

Kentucky Climate Center 2001. The Kentucky Climate Center at Western Kentucky University Station Climate Summaries—Eastern Kentucky University Station. Accessed 25 Nov 2004 at: http://kyclim.wku.edu/cgi-bin/stations/152409

[KY-EPPC] Kentucky Exotic Pest Plant Council. 2001. Southeast Exotic Pest Plant Council: Kentucky invasive exotic plant list. Accessed 5 Dec 2004 at: http://www.invasive.org/seweeds.cfm

[KSNPC] Kentucky State Nature Preserves Commission. 2000. Rare and extirpated biota of Kentucky. J. Kentucky Acad. Sci. 61:115–132.

Keys, J. E., Jr., C. A. Carpenter, S. L. Hooks, F. G. Lienig,

W. H. McNab, W. E. Russell, and M.-L. Smith. 1995. Ecological units of the eastern United States—first approximation (map and booklet of map unit tables). U.S. Department of Agriculture, Forest Service, Atlanta, GA.

MacGregor, J. R. 1983. Two new orchid records from Harlan County, Kentucky. Trans. Kentucky Acad. Sci. 44:90.

Martin, W. H., W. S. Bryant, S. J. Lassetter, and J. B. Varner. 1979. The Kentucky River Palisades flora and vegetation. Kentucky Chapter of the Nature Conservancy, Frankfort, KY.

Preston, D. G., R. P. Sims, A. J. Richardson, R. L. Blevins, and J. E. Taylor. 1964. Soil survey of Clark County, Kentucky. U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.

Rafaill, B. L., and R. L. Thompson. 2002. Vascular flora of the Henderson Fork Road Surface-mined area, Bell County, Kentucky. J. Kentucky Acad. Sci. 63:53–64.

Reinking, M. F. 1979. A floristic analysis of two abandoned limestone quarries on Kelleys Island, Erie County, Ohio. M.S. Thesis. Ohio State Univ., Columbus, OH.

Ross, J. J. 1970. A vascular flora of the limestone quarry on the Marblehead Peninsula, Ottawa County, Ohio. M.S. Thesis. Ohio State Univ., Columbus, OH.

Thompson, R. L., and E. W. J. FitzGerald, Jr. 2003. Vascular flora of Feltner Lake, Laurel County, Kentucky. J. Kentucky Acad. Sci. 64:75–92.

Thompson, R. L., and J. R. MacGregor. 1986. *Liparis loeselii* (Orchidaceae) documented in Kentucky. Trans. Kentucky Acad. Sci. 47:138–139.

Thompson, R. L., and G. L. Wade. 1991. Flora and vegetation of a 12-year-old coal surface-mined area in Rockcastle County, Kentucky. Castanea 56:99–116.

Thompson, R. L., G. L. Wade, and R. A. Straw. 1996. Natural and planted flora of the Log Mountain Surface-mined Demonstration Area, Bell County, Kentucky. Pages 484–503 in Proceedings, 13th Annual National Meeting American Society for Surface Mining and Reclamation, May 18–22, 1996, Knoxville, TN.

Thompson, R. L., W. G. Vogel, and D. D. Taylor. 1984. Vegetation and flora of a coal surface-mined area in Laurel County, Kentucky. Castanea 49:111–126.

Trewartha, G. T., and L. H. Horn. 1980. An introduction to climate, 5th ed. McGraw-Hill Book Co., New York, NY.

Usher, M. B. 1979. Natural communities of plants and animals in disused quarries. J. Environ. Managem. 8: 223–236.

Wade, G. L., and R. L. Thompson. 1993. Species richness on five partially reclaimed Kentucky surface mines. Pages 307–314 in Proceedings, 10th Annual National Meeting American Society for Surface Mining and Reclamation, May 16–19, 1993, Spokane, WA.

Wade, G. L., and R. L. Thompson. 2002. Flora of the Fonde Surface Mine Demonstration Area, Bell County, Kentucky. Pages 674–701 in Proceedings, 19th Annual National Conference, American Society of Mining and Reclamation, June 9–13, 2002, Lexington, KY.

Wharton, M. E., and R. W. Barbour. 1991. Bluegrass land & life—land character, plants, and animals of the Inner Bluegrass Region of Kentucky past, present, and future. Univ. Press Kentucky, Lexington, KY.

Woods, A. J., J. M. Omernik, W. H. Martin, G. J. Pond, W. M. Andrews, S. M. Call, J. A. Comstock, and D. D. Taylor. 2002. Ecoregions of Kentucky (color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, (map scale 1:000,000), Reston, VA.

Appendix: The Annotated Plant List

The annotated list, arranged alphabetically by family and species, includes the scientific name, habitat(s), relative abundance, and collection number for each taxon. An asterisk (*) precedes an exotic species. Two asterisks (**) precede a Kentucky invasive exotic pest plant. A dagger (†) precedes a Clark County distribution record based on Braun (1943), Beckett (1956), Beal and Thieret (1986), and a specimen search at BEREA, EKY, and University of Kentucky (UK). The scientific name is followed by the major plant habitat(s). The five major habitats in the Clark County abandoned quarry are assigned a numbered code: (1) Xeric Vertical Highwall, (2) Mesic Highwall Talus Slope, (3) Permanent Pool and Drainage Ditch, (4) Subxeric Quarry Floor and Haul Road, and (5) Elevated Spoil Pile.

Relative abundance follows the habitat(s) designations. Relative abundance values are determined through field observations of number of individuals or colonies of each taxon in the habitats of the quarry. One relative abundance value is assessed for each species and is inclusive for all specific habitats in which the species is found. Relative abundance categories from Thompson and FitzGerald (2003) are *Rare* (R) 1–5 individuals or colonies in the quarry, *Infrequent* (I) 6–30 individuals or colonies in the quarry, *Occasional* (O) 31–100 individuals or colonies in the quarry, *Frequent* (F) 101–1000 individuals or colonies in the quarry, and *Abundant* (A) more than 1000 individuals or colonies in the quarry.

A plant collection number is given after the relative abundance value in italics. This number lists the year collected, followed by a hyphen, and then the actual specimen number, (e.g., *99-985*). All individuals present on col-

lecting trips are listed on the herbarium specimen labels.

Equisetophyta

Equisetaceae
†*Equisetum arvense* L. 3; F. *94-203*
†*Equisetum hyemale* L. 3; F. *97-555*

Polypodiophyta

Aspleniaceae
Asplenium platyneuron (L.) BSP. 1, 2; I. *93-400*
Polystichum acrostichoides (Michx.) Schott 2; R. *94-435*

Pinophyta

Cupressaceae
Juniperus virginiana L. 1, 2, 4, 5; F. *93-298*

Magnoliophyta—Magnoliopsida

Acanthaceae
Ruellia strepens L. 2; R. *97-557*
Aceraceae
Acer negundo L. 2, 3, 4, 5; F. *93-281*
Acer saccharinum L. 2, 3, 5; O. *94-243*
Acer saccharum Marsh. 2, 4, 5; F. *93-280*
Anacardiaceae
Rhus aromatica Ait. 4; I. *97-556*
Rhus glabra L. 4; I. *93-279*
Toxicodendron radicans (L.) Kuntze 1, 2, 4, 5; F. *93-278*
Apiaceae
Chaerophyllum procumbens (L.) Crantz 2; I. *94-208*
†*Cicuta maculata* L. 3; R. *93-406*
Cryptotaenia canadensis (L.) DC. 2; R. *93-277*
****Daucus carota* L. 1, 2, 4, 5; F. *97-686*
Osmorhiza longistylis (Torr.) DC. 2; R. *94-221*
**Pastinaca sativa* L. 4, 5; O. *97-560*
Sanicula canadensis L. 2; R. *93-275*
†*Sanicula gregaria* Bickn. 2; I. *97-635*
†**Torilis arvensis* (Huds.) Link 4, 5; I. *97-630*
Apocynaceae
Apocynum cannabinum L. 3, 5; O. *94-431*
Asclepiadaceae
Ampelamus albidus (Nutt.) Britt. 2; R. *93-607*
Asclepias incarnata L. 3; R. *93-425*
Asclepias syriaca L. 4; R. *93-307*
Asclepias tuberosa L. 4; R. *93-301*
Asclepias viridis Walt. 2; R. *94-432*
Asteraceae
**Achillea millefolium* L. 4; I. *93-205*
Ambrosia artemisiifolia L. 1, 2, 4, 5; F. *93-584*
Aster cordifolius L. 2, 4; O. *96-603*
Aster lateriflorus (L.) Britt. 2, 5; O. *93-781*
†*Aster novae-angliae* L. 4, 5; F. *98-815*
Aster pilosus Willd. 1, 4, 5; F. *93-755*
Aster shortii Lindl. 2, 4; I. *99-982*
†*Bidens comosa* (A. Gray) Wieg. 3; F. *96-607*
Bidens frondosa L. 3; O. *93-776*
Bidens polylepis S.F. Blake 3; I. *96-608*
†***Carduus nutans* L. 5; R. *93-273*
***Chrysanthemum leucanthemum* L. 1, 4, 5; O. *93-206*
**Cichorium intybus* L. 4, 5; O. *93-270*
Cirsium discolor (Muhl.) Spreng. 4, 5; O. *99-994*
**Cirsium vulgare* (Savi) Tenore 5; R. *99-980*
Conyza canadensis (L.) Cronq. 1, 4, 5; O. *96-602*
†**Crepis pulchra* L. 2; R. *97-568*
Erigeron annuus (L.) Pers. 4, 5; O. *97-561*
Erigeron philadelphicus L. 4; R. *94-239*
Erigeron strigosus Muhl. 4; I, *97-558*
Eupatorium fistulosum Barratt 2, 3, 5; O. *99-985*
†*Eupatorium hyssopifolium* L. 4; O. *98-910*
Eupatorium perfoliatum L. 3; I. *93-768*
Eupatorium rugosum Houtt. 2, 5; F. *99-979*
Eupatorium serotinum Michx. 3, 5; I. *96-611*
Euthamia graminifolia (L.) Nutt. 3; I. *93-782*
Helenium autumnale L. 3; R. *98-918*
†*Helianthus decapetalus* L. 2; R. *93-603*
Kuhnia eupatorioides L. 4; O. *99-998*
Lactuca canadensis L. 2, 4, 5; I. *93-269*
Lactuca floridana (L.) Gaertn. 2; R. *93-606*
**Lactuca serriola* L. 5; I. *98-902*
Polymnia canadensis L. 2; I. *96-599*
Senecio glabellus Poir. 3; R. *98-155*
Solidago canadensis L. 2, 4, 5; O. *99-970*
Solidago gigantea Ait. 5; R. *99-917*
Solidago nemoralis Ait. 4; O. *98-921*
**Sonchus asper* (L.) Hill 4, 5; I. *96-600*
**Taraxacum officinale* Weber 2, 4, 5; O. *98-29*
**Tragopogon dubius* Scop. 4; R. *93-295*
†**Tussilago farfara* L. 5; O. *98-145*

†*Verbesina alternifolia* (L.) Britt. 2, 5; I. *99-983*
Vernonia gigantea (Walt.) Trel. 2, 4; I. *96-616*
Balsaminaceae
Impatiens capensis Meerb. 1, 2, 3, 5; A. *99-988*
Impatiens pallida Nutt. 2; O. *93-484*
Betulaceae
Carpinus caroliniana Walt. 2; R. *94-660*
Ostrya virginiana (Mill.) K. Koch 2; R. *97-687*
Bignoniaceae
Bignonia capreolata L. 1, 2; I. *94-216*
Campsis radicans (L.) Seem. 1, 2, 4; I. *93-293*
Brassicaceae
†***Alliaria petiolata* (Bieb.) Cavara & Grande 2; R. *97-278*
Arabis laevigata (Muhl.) Poir. 1, 2; R. *94-206*
Cardamine concatenata (Michx.) Schwartz 2; R. *98-28*
†**Cardamine hirsuta* L. 2, 4, 5; F. *95-26*
Cardamine pensylvanica Muhl. 3; R. *94-236*
**Draba verna* L. 4, 5; O. *95-27*
Lepidium virginicum L. 4; I. *93-775*
**Thlaspi perfoliatum* L. 4: I. *94-146*
Campanulaceae
Campanula americana L. 2; R. *97-675*
Lobelia inflata L. 4, 5; R. *93-427*
Lobelia siphilitica L. 3, 5; I. *98-907*
Caprifoliaceae
***Lonicera japonica* Thunb. 1, 2, 4, 5; F. *94-440*
†***Lonicera maackii* (Rupr.) Maxim. 1, 4, 5; F. *99-987*
Sambucus canadensis L. 2; R. *94-442*
Symphoricarpos orbiculatus Moench 4; I. *94-429*
Viburnum rufidulum Raf. 2, 4; R. *94-231*
Caryophyllaceae
**Cerastium vulgatum* L. 4, 5; O. *94-207*
**Dianthus armeria* L. 4; I. *97-563*
**Saponaria officinalis* L. 2; O. *98-911*
**Silene latifolia* Poir. 2; R. *97-637*
***Stellaria media* (L.) Villars 2, 4, 5; F. *98-30*
Celastraceae
Celastrus scandens L. 2, 4; I. *93-801*
Euonymus atropurpureus Jacq. 2, 4; R. *97-562*
Chenopodiaceae
†**Chenopodium album* L. 5; R. *96-606*
Clusiaceae
Hypericum mutilum L. 3; O. *93-416*
Hypericum punctatum Lam. 4; R. *97-678*
Cornaceae
Cornus drummondii C. A. Mey. 2, 3, 4, 5; F. *99-971*
Crassulaceae
Sedum pulchellum Michx. 2, 4; O. *97-575*
Dipsacaceae
***Dipsacus sylvestris* Huds. 5; I. *97-685*
Euphorbiaceae
†*Acalypha virginica* L. 4, 5; I. *93-778*
†*Croton monanthogynus* Michx. 5; I. *96-609*
Euphorbia corollata L. 4; R. *93-399*
Euphorbia dentata Michx. 4, 5; I. *93-586*
†*Euphorbia maculata* L. 4, 5; I. *93-422*
Euphorbia nutans Lag. 4, 5; O. *93-627*
Fabaceae
Amphicarpaea bracteata (L.) Fern. 2; O. *94-729*
Cercis canadensis L. 2, 4, 5; O. *93-291*
†***Coronilla varia* L. 4, 5; O. *97-579*
†*Desmodium viridiflorum* (L.) DC. 2, 4; I. *93-758*
†***Lespedeza cuneata* (Dum. Cours.) G. Don 1, 4, 5; F. *93-585*
†***Lespedeza stipulacea* Maxim. 4, 5; F. *93-591*
†**Medicago lupulina* L. 4, 5; O. *97-565*
***Melilotus alba* Medic. 1, 2, 4, 5; O. *97-566*
***Melilotus officinalis* (L.) Pallis 4; R. *93-290*
Robinia pseudoacacia L. 2, 4, 5; F. *98-149*
**Trifolium campestre* Schreb. 4, 5; I. *93-232*
**Trifolium hybridum* L. 5; R. *98-154*
**Trifolium pratense* L. 2, 4, 5; O. *96-615*
†**Trifolium repens* L. 4, 5; I. *97-567*
†**Vicia sativa* L. 4; R. *93-260*
Fagaceae
Quercus muhlenbergii Engelm. 2, 4; I. *94-441*
Quercus shumardii Buckl. 2, 4; I. *94-427*
Hippocastanaceae
Aesculus glabra Willd. 2, 3, 4; I. *93-259*
Hydrangeaceae
Hydrangea arborescens L. 2; R. *93-261*
Hydrophyllaceae
Phacelia bipinnatifida Michx. 2; I. *97-279*

Juglandaceae
Juglans nigra L. 2; R. *97-622*
Lamiaceae
Hedeoma pulegioides (L.) Pers. 1, R. *93-628*
**Lamium amplexicaule* L. 5; R. *95-25*
**Lamium purpureum* L. 5; I. *98-27*
†*Lycopus americanus* Muhl. 3; O. *98-919*
***Mentha ×piperita* L. 3; O. *99-978*
Prunella vulgaris L. 3, 4, 5; O. *97-689*
Scutellaria lateriflora L. 3; I. *99-973*
Lauraceae
Sassafras albidum (Nutt.) Nees 4; R. *94-232*
Menispermaceae
Menispermum canadense L. 2; I. *93-802*
Moraceae
***Morus alba* L. 4, 5; I. *93-256*
Oleaceae
†***Ligustrum obtusifolium* Sieb. & Zucc. 2; R. *94-212*
Fraxinus americana L. 2, 4; O. *94-219*
Fraxinus pennsylvanica Marsh. 2, 3, 4; O. *93-255*
Fraxinus quadrangulata Michx. 2; I. *94-408*
Onagraceae
†*Epilobium coloratum* Biehler 3; O. *99-989*
Ludwigia alternifolia L. 3; I. *93-488*
Oenothera biennis L. 4, 5; O. *98-901*
Oxalidaceae
Oxalis stricta L. 2, 4, 5; O. *93-423*
Papaveraceae
Sanguinaria canadensis L. 2; R. *98-31*
Phytolaccaceae
Phytolacca americana L. 2, 5; I. *93-648*
Plantaginaceae
**Plantago lanceolata* L. 4, 5; O. *97-680*
Plantago rugelii Dcne. 4, 5; I. *97-688*
†*Plantago virginica* L. 5; I. *97-570*
Platanaceae
Platanus occidentalis L. 2, 3, 4, 5; F. *93-287*
Polygonaceae
†***Polygonum cespitosum* Blume var. *longisetum* (De Bruyn) Steward 3, 5; O. *93-604*
***Polygonum persicaria* L. 2, 5; O. *99-991*
**Rumex crispus* L. 2; I. *93-248*
†**Rumex obtusifolius* L. 2, 3, 5; O. *97-676*
Primulaceae
†**Lysimachia nummularia* L. 3; O. *94-222*
Ranunculaceae
Anemone virginiana L. 2; I. *93-598*
Aquilegia canadensis L. 1; R. *94-142*
Clematis virginiana L. 2; I. *94-225*
Delphinium tricorne Michx. 2; R. *94-136*
Ranunculus recurvatus Poir. 2; I. *94-227*
Thalictrum dioicum L. 2; R. *94-215*
Rosaceae
Fragaria virginiana Duchesne 4; O. *93-223*
Geum canadense Jacq. 2; I. *97-634*
Geum vernum (Raf.) Torr. & A. Gray 2; I. *94-286*
†**Potentilla norvegica* L. 5; R. *97-625*
**Prunus mahaleb* L. 4; O. *98-146*
Prunus serotina Ehrh. 2, 4, 5; O. *94-234*
†**Pyrus communis* L. 2; R. *93-629*
†**Pyrus malus* L. 4; R. *94-228*
†***Rosa multiflora* Thunb. 4, 5; O. *99-990*
Rubus occidentalis L. 2, 4, 5; O. *93-242*
Rubiaceae
Galium aparine L. 2, 4, 5; O. *94-223*
Galium circaezans Michx. 4; R. *94-446*
Galium tinctorium L. 3; F. *93-241*
Salicaceae
†*Populus deltoides* Marsh. 3; R. *93-222*
†*Salix exigua* Nutt. 3; F. *94-213*
Salix nigra Marsh. 2, 3; F. *94-240*
Scrophulariaceae
Aureolaria virginica (L.) Pennell 4; R. *96-604*
Leucospora multifida (Michx.) Nutt. 4; O. *97-580*
Mimulus alatus Ait. 3; I. *93-404*
†*Mimulus ringens* L. 3; O. *98-922*
Penstemon pallidus Small 4; I. *97-576*
**Verbascum thapsus* L. 4, 5; O. *97-690*
**Veronica anagallis-aquatica* L. 3; O. *98-153*
**Veronica arvensis* L. 4, 5; F. *94-229*
†**Veronica peregrina* L. 3, 5; I. *94-202*
Staphyleaceae
Staphylea trifolia L. 2; R. *94-242*
Ulmaceae
Celtis occidentalis L. 2, 4; I. *93-238*
Ulmus americana L. 2, 4; I. *94-238*
Ulmus rubra Muhl. 2, 4, 5; F. *94-233*
Urticaceae
†*Boehmeria cylindrica* (L.) Sw. 2, 4; O. *93-602*
Laportea canadensis (L.) Wedd. 2; I. *93-454*
Parietaria pensylvanica Muhl. 2; I. *98-906*
Pilea pumila (L.) A. Gray 2, 3; O. *93-600*
Valerianaceae
†*Valerianella umbilicata* (Sulliv.) A. Wood 2; R. *94-204*
Verbenaceae
Verbena simplex Lehm. 4; I. *97-577*
Verbena urticifolia L. 2, 5; R. *97-679*

Vitaceae
Parthenocissus quinquefolia (L.) Planch. 1, 2, 4; O. *93-237*
Vitis vulpina L. 1, 2, 4; O. *93-410*

Magnoliophyta—Liliopsida

Alismataceae
Alisma subcordatum Raf. 3; F. *99-986*
Sagittaria australis (J.G. Smith) Small 3; O. *93-402*
Cyperaceae
Carex blanda Dewey 2; R. *94-447*
†*Carex cristatella* Britt. 3; O. *97-627*
†*Carex grisea* Wahlenb. 2; R. *94-452*
Carex frankii Kunth 3; O. *97-624*
Carex lurida Wahlenb. 3; F. *97-631*
Carex vulpinoidea Michx. 3; F. *97-633*
†*Cyperus odoratus* L. 3; R. *93-751*
Cyperus strigosus L. 3; I. *93-780*
†*Eleocharis ovata* (Roth) Roem. & Schultes 3; I. *96-595*
Scirpus atrovirens Willd. 3; F. *97-623*
†*Scirpus cyperinus* (L.) Kunth 3; F. *93-760*
†*Scirpus pendulus* Muhl. 3; I. *97-628*
Scirpus validus Vahl 3; I. *98-905*
Iridaceae
Sisyrinchium angustifolium P. Mill. 2; R. *97-632*
Juncaceae
Juncus acuminatus Michx. 3; O. *93-258*
Juncus effusus L. var. *solutus* Fern. & Wieg. 3; F. *93-288*
Juncus tenuis Willd. var. *dudleyi* (Wieg.) F.J. Herm. 3, 4; O. *97-629*
Lemnaceae
Lemna minor L. 3; A. *97-569*
Liliaceae
†*Allium canadense* L. 2; R. *97-636*
Orchidaceae
†*Liparis loeselii* (L.) Rich. 3; I. *94-701*
†*Spiranthes lucida* (H. Eat.) Ames 3; R. *94-426*
Poaceae
**Agrostis gigantea* Roth 2, 3; I. *97-682*
Andropogon virginicus L. 4; F. *96-593*
**Bromus japonicus* Thunb. 5; I. *97-571*
Bromus pubescens Muhl. 2; R. *94-451*
**Bromus tectorum* L. 4; I. *94-237*
Chasmanthium latifolium (Michx.) Yates 2; I. *93-417*
Cinna arundinacea L. 3; R. *93-415*
**Dactylis glomerata* L. 1, 2, 4; O. *93-230*
Elymus hystrix L. 2; R. *93-229*
Elymus virginicus L. 2; I. *97-677*
†*Eragrostis pectinacea* (Michx.) Nees 4; I. *93-769*
***Festuca elatior* L. 1, 2, 4, 5; A. *94-650*
†**Festuca ovina* L. 4; R. *93-226*
Festuca subverticillata (Pers.) E. Alexeev. 2; R. *94-448*
Glyceria striata (Lam.) Hitchc. 3; F. *93-251*
Leersia oryzoides (L.) Sw. 3; F. *93-777*
***Microstegium vimineum* (Trin.) A. Camus 1, 2, 4, 5; A. *93-762*
Panicum boscii Poir. 2; R. *93-250*
Panicum capillare L. 4; R. *96-597*
Panicum dichotomiflorum Michx. 3; I. *93-767*
Panicum flexile (Gattinger) Scribn. 4; F. *98-923*
**Phleum pratense* L. 4; R. *93-599*
**Poa annua* L. 4, 5; O. *94-149*
**Poa compressa* L. 2, 4; O. *97-574*
†**Secale cereale* L. 5; R. *98-151*
**Setaria faberi* E. Herrm. 5; I. *93-588*
**Setaria glauca* (L.) P. Beauv. 5; R. *94-702*
***Sorghum halepense* (L.) Pers. 4, 5; I. *98-900*
Tridens flavus (L.) A. Hitchc. 4; O. *96-591*
†**Triticum aestivale* L. 5; R. *98-152*
Smilacaceae
Smilax bona-nox L. 2; R. *93-303*
Typhaceae
Typha latifolia L. 3; A. *99-993*

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Floristic Survey of Indian Fort Amphitheater, Berea College Forest, Madison County, Kentucky

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ABSTRACT

The vascular flora of the 49-year-old Indian Fort amphitheater, Berea College Forest, in Madison County, south-central Kentucky, was surveyed in 1999, 2000, 2002, 2003, and 2004. Seventy-four species in 55 genera from 30 families were present; 40 species (54.0%) were exotics. Life forms included 39 annual/biennials, 24 perennials, 6 woody vines, and 5 trees. Many taxa were ruderal weeds that had adapted to the open physical features and disturbed environmental conditions of the amphitheater. These plants typically have light-weight fruits and seeds dispersed by wind and water.

INTRODUCTION

Few studies have been conducted on vascular plants that have invaded urban areas as a result of specialized microhabitats created by people. Previous studies have included vegetation of footpaths, sidewalks, cart-tracks, and gateways in England (Bates 1935), weeds from a race track in North Dakota (Stevens 1969), plants from sidewalks and parking lots in Georgia (Duncan and Meyer 1969; Meyer 1967), and the flora of sidewalk crevices in South Carolina (Westbrooks 1978, 1981). Other anthropogenic-related habitats for plant establishment have been railroad track ballast and railroad right-of-ways in Illinois (Thompson and Heineke 1977) and Missouri (Mühlenbach 1979, 1983; Thompson 1979).

The Indian Fort Theatre (hereafter, Indian Fort amphitheater or amphitheater) in the 3318-ha (8200 acre) Berea College Forest has provided an unusual and unique microhabitat for the establishment of ruderal vascular plants in south-central Kentucky. The 49-year-old open outdoor amphitheater is located entirely within forested terrain 4.2 km from Berea, Kentucky, and 0.4 km north of Kentucky Highway 21 in Madison County. The amphitheater was initially built from June 1954 to February 1955 for the set and presentation of *Wilderness Road* (Green 1956), a symphonic outdoor drama with a Civil War setting. The drama was presented in summers 1955 through 1958, and again in summers from 1972 through 1980. The amphitheater continues to be used for concerts, reunions, religious and educational gatherings, craft fairs, and other recreational purposes.

The isosceles trapezoid-shaped amphitheater measures 24.7 m at the front, 47.5 m at the back, and 34.1 m at the 0.8 m deep sunken sides. It is located at the end of an asphalt trail 0.2 km north from a gravel and paved parking lot. The amphitheater, covering a surface area of 0.12 ha (0.29 acres), is an east-southeast trending limestone structure entirely exposed to the sun and elements of weather. Inside are 33 rising tiers of steps of flattened limestone rocks cemented together with the tops covered with concrete. These steps measure 28 cm high and 91 cm wide. A 0.2-km cinder maintenance road leads north from another gravel parking lot to the grassy front-stage area.

The major microhabitats that have developed on the inside of the amphitheater over time are crevices and cracks usually less than 0.5 cm wide. These microhabitats are especially evident at the surfaces between the front of each step with the adjoining tier of the next step. Plants have become established and persisted through dry weather, hot sun exposure without any shade, and human disturbances of trampling, cement regrouting, herbicides, and string-trimming. In 2001, most crevices and cracks in the tops and sides of the steps were regrouted with cement. In addition, plants growing from the seed bank after 2001 were sprayed with Roundup® herbicide in spring 2002, 2003, and 2004. Plants germinating after herbicide treatment were then string-trimmed in mid-to-late summer during those same years.

The objectives of this floristic survey are to document the vascular plants from the Indian

Fort amphitheater with voucher specimens and to compile an annotated species list with origin (exotic or native), relative abundance, and life form for each taxon.

THE ENVIRONMENTAL COMPLEX

Indian Fort amphitheater is contiguous to a stand of white oak-mixed hickory-Virginia pine forest at 305 m (1000 feet) elevation on the 473 m (1552 feet) Indian Fort Mountain. The study area is situated within the Knobs-Lower Scioto Dissected Plateau ecoregion of Woods et al. (2002). A tall fescue-red clover grass border lies directly adjacent to the sides and the open stage front. Braun (1950) placed the forest vegetation of the Knobs region within the Western Mesophytic Forest Region. The forest vegetation here is best representative of the white oak upland forest type of Muller and McComb (1986). The distribution of plant species within the Knobs has been shown to be related to parent material, soils, physical site conditions, and vegetation (Braun 1950; Muller and McComb 1986).

Geology of the adjacent terrain is composed of yellowish brown and yellowish gray siltstones interstratified with gray silty shales. This bedrock belongs to the Nancy Member of the Borden Formation in the Mississippian System (Weir et al. 1971). Forest soils belong to the Colyer-Weikert-Captina Association, and the soil series on the 6–12% slopes and toeslopes of the amphitheater area are brown Captina silt loams. Captina silt loams are very acidic and moderately well drained, have a fragipan at 50 cm, and contain a mixture of siltstone and shale pebbles in the subsoil (Newton et al. 1973).

METHODS

Vascular plants were collected from the amphitheater during 21 field trips in 1999, 2000, 2002, 2003, and 2004. No collections were made in 2001 because of the regrouting and recementing of the steps. Representative voucher specimens of each species are deposited in the Berea College Herbarium. Plants outside the limestone amphitheater were observed but not included in the species list. The Gleason and Cronquist (1991) manual was used for identification, nomenclature, and common names; authors' names follow Brummitt and Powell (1992). The list of species includes the scientific name, plant origin (exotics preceded by an asterisk), common name, life form (annual/biennial, perennial herb, woody vine, or tree), relative abundance value, and voucher collection number(s) for each taxon. A relative abundance scale (frequency of occurrence) for plants in the study area is: rare (1–2 plants); infrequent (3–15 plants); occasional (16–39 plants); and frequent (over 40 plants).

RESULTS AND DISCUSSION

Seventy-four vascular plant species in 55 genera from 30 families were collected within the limestone-based amphitheater. Forty species (54.0%) were exotics. Life forms consist of 39 annuals/biennials (27 exotics), 24 perennials (9 exotics), six woody vines (3 exotics), and five trees (1 exotic). All plants were collected in flowering and fruiting condition except for seven herbs and the 11 species of woody plants. The families with the most species were Asteraceae (14) and Poaceae (13). These two families also accounted for the most species in Duncan and Meyer (1969), Thompson (1979), Thompson and Heineke (1977), and Westbrooks (1981).

Frequent species in relative abundance were *Arenaria serpyllifolia, Cerastium viscosum, Digitaria sanguinalis, Euphorbia maculata, Medicago lupulina, Oxalis stricta,* and *Sonchus asper.* Thirty-nine taxa are rare in relative abundance. Six of the 11 woody species were represented by only a single plant: *Celastrus orbiculatus, Liriodendron tulipifera, Platanus occidentalis, Toxicodendron radicans, Vinca minor,* and *Vitis vulpina.*

Taxa with occasional and frequent relative abundance were mostly "weeds" or ruderal species—those taxa inhabiting areas with anthropogenic effects. Several native and exotic weedy species are adapted to trampling effects by people partly because of their growth habit (basal, cespitose, decumbent, prostrate), e.g., *Digitaria sanguinalis, Eleusine indica, Eragrostis pectinacea, Euphorbia maculata, Juncus tenuis, Plantago rugelii, Poa annua, Polygonum aviculare,* and *Taraxacum officinale.*

The species richness of the study area is directly related to those species present in the adjoining forest, grass border, asphalt trail edges, and the cinder road. These habitats provide plant propagules or diaspores in the

seed bank for colonization. All 11 woody taxa were present in the surrounding forest. Most annuals and perennials collected within the amphitheater were observed in the grass border and cinder road and along the asphalt trail edges, e.g., members of Asteraceae, Caryophyllaceae, Fabaceae, Lamiaceae, Plantaginaceae, and Poaceae.

The occurrence, establishment, and persistence of plants can be determined partly by the type of propagules they possess. Most species in the amphitheatre have small, lightweight propagules that can be easily carried by wind and rain run-off. Wind-dispersed fruits and seeds include members of Asteraceae, Brassicaceae, Caryophyllaceae, Magnoliaceae, Platanaceae, Scrophulariaceae, and several other families. Some woody plants have spread vegetatively from the actual plantings of the background set construction through cracks in the steps, e.g., *Euonymus fortunei, Populus alba,* and *Vinca minor.* Some propagules have inadvertently been carried by humans into the amphitheater, e.g., on shoes and in pant cuffs, and in animal droppings. Wind and water are the two most important factors for the transportation of soil into the crevices and cracks of the steps for plant establishment.

The 74 vascular plant species compared favorably with the urban studies of Duncan and Meyer (1969) with 78 species, Stevens (1969) with 40 species, and Westbrooks (1981) with 36 species. Weedy native and exotic annuals made up a majority of species in those studies. Although the flora of these three studies was comprised of relatively few species, they were species highly adaptable to open disturbed environments.

ANNOTATED SPECIES LIST

Exotics are indicated by an asterisk.

Acanthaceae

Ruellia carolinensis (Walter) Steud. Wild petunia. Perennial; rare. *99–2017.*

Anacardiaceae

Toxicodendron radicans (L.) Kuntze. Poison-ivy. Woody vine; rare. *02–353.*

Apocynaceae

**Vinca minor* L. Lesser periwinkle. Woody vine; rare. *99–2002.*

Asteraceae

Aster lateriflorus (L.) Britton. Calico Aster. Perennial; infrequent. *99–2010; 03–1236.*

Bidens bipinnata L. Spanish needles. Annual; rare. *99–2014; 04–1124.*

Bidens frondosa L. Devil's beggar-ticks. Annual; rare. *04–1411.*

**Cirsium vulgare* (Savi) Ten. Bull thistle. Biennial; rare. *03–822.*

Conyza canadensis (L.) Cronquist. Horseweed. Annual; infrequent. *03–435.*

Erechtites hieraciifolia (L.) Raf. Fireweed. Annual; rare. *04–1398.*

Erigeron annuus (L.) Pers. Annual fleabane. Annual; occasional. *04–624.*

Erigeron philadelphicus L. Philadelphia daisy. Perennial; occasional. *00–116; 04–244.*

Eupatorium coelestinum L. Blue mist-flower. Perennial; rare. *04–1405.*

**Galinsoga quadriradiata* Ruiz. & Pavon. Quickweed. Annual; rare. *04–1399.*

**Lactuca saligna* L. Willowleaf-lettuce. Annual/biennial; occasional. *99–2005; 04–1173.*

Senecio anonymus A.W. Wood. Appalachian groundsel. Perennial; rare. *00–118.*

**Sonchus asper* (L.) Hill. Prickly sow-thistle. Annual; frequent. *99–2009; 03–26.*

**Taraxacum officinale* F.H. Wigg. Common dandelion. Perennial; infrequent. *99–2016.*

Bignoniaceae

Campsis radicans (L.) Seem. Trumpet-creeper. Woody vine; infrequent. *99–2018.*

Brassicaceae

**Cardamine hirsuta* L. Hoary bitter-cress. Annual; infrequent. *02–23.*

**Draba verna* L. Whitlow-grass. Annual; rare. *00–121.*

Lepidium virginicum L. Poor-man's pepper. Annual/biennial; infrequent. *02–430.*

Campanulaceae

Triodanis perfoliata (L.) Nieuwl. Round-leaved triodanis. Annual; infrequent. *00–114.*

Caryophyllaceae

**Arenaria serpyllifolia* L. Thyme-leaved sandwort. Annual; frequent. *00–113; 03–20.*

**Cerastium viscosum* L. Clammy chickweed. Annual; frequent. *02–10.*

**Stellaria media* (L.) Vill. Common chickweed. Annual; infrequent. *02–18.*

Celastraceae

**Celastrus orbiculatus* Thunb. Oriental bittersweet. Woody vine; rare. *03–436.*

**Euonymus fortunei* (Turcz.) Hand.-Mazz. Winter-creeper. Woody vine; rare. *99–2001.*

Cyperaceae

Carex blanda Dewey. Eastern woodland sedge. Perennial; rare. *04–1471.*

Euphorbiaceae

Acalypha rhomboidea Raf. Rhombic copperleaf. Annual; infrequent. *03–1371.*

Euphorbia maculata L. Spotted spurge. Annual; frequent. *99–2007; 04–1408.*

Euphorbia nutans Lag. Eyebane. Annual; occasional. *99–2008; 02–351.*

Fabaceae

**Lespedeza striata* (Thunb.) Hook. & Arn. Japanese lespedeza. Annual; rare. *02–357.*

**Medicago lupulina* L. Black medick. Annual; frequent. *00–119; 02–20.*

Robinia pseudoacacia L. Black locust. Tree; rare. *04–1412.*

**Trifolium campestre* Schreb. Pinnate hop-clover. Annual; rare. *00–122.*

**Trifolium pratense* L. Red clover. Perennial; rare. *04–1175.*

**Trifolium repens* L. White clover. Perennial; rare. *03–23.*

Geraniaceae

**Geranium columbinum* L. Long-stalk crane's-bill. Perennial; rare. *00–117; 03–21.*

Hamamelidaceae

Liquidambar styraciflua L. Sweetgum. Tree; rare. *04–1177.*

Juncaceae

Juncus tenuis Willd. Path rush. Perennial; rare. *02–25.*

Lamiaceae

**Ajuga reptans* L. Carpet-bugle. Perennial; rare. *00–1247.*

**Lamium amplexicaule* L. Henbit. Annual; rare. *02–22.*

**Lamium purpureum* L. Red deadnettle. Annual; rare. *02–11.*

Liliaceae

**Allium vineale* L. Field-garlic. Perennial; rare. *02–27.*

Magnoliaceae

Liriodendron tulipifera L. Tuliptree. Tree; rare. *04–625.*

Malvaceae

**Sida spinosa* L. Prickly sida. Annual; rare. *04–1176.*

Oxalidaceae

Oxalis stricta L. Common yellow wood-sorrel. Perennial; frequent. *00–115; 02–15.*

Plantaginaceae

**Plantago lanceolata* L. English plantain. Perennial; occasional. *02–16.*

Plantago rugelii Decne. Rugel's plantain. Perennial; infrequent. *02–354.*

Platanaceae

Platanus occidentalis L. American sycamore. Tree; rare. *02–360.*

Poaceae

Andropogon virginicus L. Broom-sedge. Perennial; infrequent. *04–164.*

**Digitaria ischaemum* (Schreb.) Muhl. Smooth crab-grass. Annual; occasional. *02–351.*

**Digitaria sanguinalis* (L.) Scop. Northern crab-grass. Annual; frequent. *99–2020.*

**Eleusine indica* (L.) Gaertn. Yard-grass. Annual; infrequent. *99–2005; 03–432.*

Eragrostis pectinacea (Michx.) Nees. Carolina lovegrass. Annual; infrequent. *99–2012.*

**Festuca elatior* L. Tall fescue. Perennial; rare. *03–25.*

Muhlenbergia schreberi J.F. Gmel. Nimblewill. Perennial; infrequent. *04–1410.*

Paspalum laeve Michx. Smooth bead-grass. Perennial; infrequent. *02–365.*

Paspalum pubiflorum Rupr. var. *glabrum* Vasey. Bead-grass. Perennial; infrequent. *03–434.*

**Poa annua* L. Speargrass. Annual; rare. *02–13.*

**Setaria viridis* (L.) P. Beauv. Green foxtail. Annual; infrequent. *03–433; 04–1414.*

Sporobolus vaginiflorus (Torr.) A.W. Wood. Poverty-grass. Annual; rare. *99–2003.*

Tridens flavus (L.) Hitchc. Purpletop. Perennial; rare. *04–1172.*

Polygonaceae

**Polygonum aviculare* L. Knotweed. Annual; rare. *02–352; 04–1171.*

**Polygonum cespitosum* Blume var. *longisetum* (De Bruyn) Stewart. Asiatic smart-

weed. Annual; infrequent. *02–364; 04–1409.*

Rosaceae

**Duchesnea indica* (Andrews) Focke. Indian strawberry. Perennial; rare. *04–163.*

Rubiaceae

**Galium aparine* L. Common cleavers. Annual; infrequent. *00–126; 02–17.*

**Galium pedemontanum* L. Piedmont bedstraw. Annual; occasional. *00–112; 03–24.*

Salicaceae

**Populus alba* L. Silver poplar. Tree; rare. *02–359.*

Scrophulariaceae

**Veronica arvensis* L. Corn speedwell. Annual; occasional. *00–123; 02–24.*

**Veronica hederifolia* L. Ivy-leaved speedwell. Annual; rare. *02–14.*

**Veronica peregrina* L. Purslane speedwell. Annual; infrequent. *02–12; 04–171.*

Violaceae

Viola sororia Willd. Dooryard-violet. Perennial; rare. *02–361.*

Vitaceae

Vitis vulpina L. Fox grape. Woody vine; rare. *02–358.*

SUMMARY

Seventy-four species have become established and adapted to the physical features and environmental disturbances of Indian Fort amphitheater in the Berea College Forest. Several vigorous ruderal native and exotic species flowered and set fruit even with the detrimental effects from dry hot weather, full sun exposure, trampling, regrouting, herbicides, string-trimming, and the physical aspects of limestone and concrete surfaces.

LITERATURE CITED

Bates, G. H. 1935. The vegetation of footpaths, sidewalks, cart-tracks and gateways. J. Ecol. 23:470–487.

Braun, E. L. 1950. Deciduous forests of eastern North America. Hafner Press, New York, NY.

Brummitt, R. K., and C. E. Powell. 1992. Authors of plant names. Royal Botanic Gardens, Kew, England.

Duncan, W. M., and E. C. Meyer. 1969. Vascular flora of the crevices of paved surfaces in Athens, Georgia. Bull. Georgia Acad. Sci. 27:22–40.

Gleason, H. A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd ed. New York Botanical Garden, Bronx, NY.

Green, P. E. 1956. Wilderness road: A symphonic outdoor drama. French Publishing Company, New York, NY.

Meyer, E. C. 1967. Vascular flora of the crevices of paved surfaces in Athens, Georgia. Thesis. University Georgia, Athens, GA.

Mühlenbach, V. 1979. Contributions to the synanthropic (adventive) flora of the railroads in St. Louis, Missouri, U.S.A. Ann. Missouri Bot. Gard. 66:1–108.

Mühlenbach, V. 1983. Supplement ot the contributions to the synanthropic (adventive) flora of the railroads in St. Louis, Missouri, U.S.A. Ann. Missouri Bot. Gard. 70: 170–178.

Muller, R. N., and W. C. McComb. 1986. Upland forests in the Knobs Region of Kentucky. Bull. Torrey Bot. Club 113:268–280.

Newton, J. H., H. P. McDonald, D. G. Preston, A. J. Richardson, and R. P. Sims. 1973. Soil survey of Madison County, Kentucky. U.S.D.A. Soil Conservation Service, Washington, DC.

Stevens, O. A. 1969. Weeds of an old race track in North Dakota. Castanea 34:56–58.

Thompson, R. L. 1979. Vascular flora of Cedar Gap Lake and environs, Webster and Wright counties, Missouri. Sida 8:71–89.

Thompson, R. L., and T. E. Heineke. 1977. Vascular flora of the DeSoto-Hallidayboro railroad prairie strips, Jackson County, Illinois. Trans. Illinois State Acad. Sci. 70: 114–127.

Weir, G. W., K. Y. Lee, and P. E. Cassity. 1971. Geologic map of the Bighill Quadrangle, east-central Kentucky GQ-900. U.S. Geological Survey (map scale 1:24,000), Washington, DC.

Westbrooks, R. G. 1978. A survey of the vascular flora that occur in sidewalk crevices in Orangeburg, South Carolina. Thesis. University South Carolina, Columbia, SC.

Westbrooks, R. G. 1981. Vascular flora of sidewalk crevices in Orangeburg, South Carolina. Castanea 46:109–114.

Woods, A. J., J. M. Omernik, W. H. Martin, G. J. Pond, W. M. Andrews, S. M. Call, J. A. Comstock, and D. D. Taylor. 2002. Ecoregions of Kentucky (color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey (map scale 1: 1,000,000), Reston, VA.

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Host Specificity of American Mistletoe (*Phoradendron leucarpum*, Viscaceae) in Garrard County, Kentucky

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ABSTRACT

American mistletoe (*Phoradendron leucarpum*) was observed on 1740 host trees from 12 species in 8 families in Garrard County, Kentucky. *Juglans nigra* was the predominant host tree; *Prunus serotina, Ulmus americana,* and *Robinia pseudoacacia* followed. These four host species accounted for 1560 (89.7%) of the total infested trees. American mistletoe exhibits an aggregated or clumped spatial distribution pattern among host trees, which is characteristic of its life history and avian method of dispersal. In density, the occurrence value was 3.33 infested trees per kilometer traveled.

INTRODUCTION

American mistletoe (*Phoradendron leucarpum,* Viscaceae) is an evergreen hemiparasitic shrub of several deciduous host-tree species in the eastern United States. It has long been considered an obligate hemiparasite because it obtains water and inorganic minerals from a woody host while possessing chlorophylls *a* and *b* to manufacture its own carbohydrates (Hull and Leonard 1964a, 1964b). American mistletoe (hereafter, mistletoe) ranges from eastern Texas, eastward through the Gulf States, northward from Florida to southern New Jersey, southeastern Pennyslvania, and West Virginia, westward to southern Ohio, Indiana, Illinois, and Missouri, thence to eastern Oklahoma (Kuijt 2003; Scharpf and Hawksworth 1974).

Until 1989, American mistletoe had been referred to as *Phoradendron serotinum* (Raf.) M. C. Johnston in most manuals and floras of the eastern United States. Reveal and Johnston (1989) gave the correct nomenclature as *Phoradendron leucarpum* (Raf.) Reveal & M. C. Johnst. Kuijt (2003) recognized American mistletoe as *Phoradendron serotinum* (Raf.) M. C. Johnst. var. *serotinum.*

To date, three mistletoe studies have been published in Kentucky (Reed and Reed 1951; Thompson 1992; Thompson and Noe 2003). As part of this ongoing research, we conducted a survey of host trees infested with *Phoradendron leucarpum* in Garrard County, Kentucky. The first report for mistletoe in Garrard County was a sight record by Braun (1943). Mistletoe had been observed in Garrard County on *Juglans nigra, Prunus serotina,* and *Ulmus americana* by Reed and Reed (1951).

THE STUDY AREA

Garrard County is located in central Kentucky and comprises 606 km^2, of which 599 km^2 is land and 7 km^2 is water. Lancaster, the county seat, is located at latitude 37°37′07″N and longitude 84°34′46″W. In the 2000 census, the population of Garrard County was 14,492 people, with 3734 people in Lancaster (Wikipedia 2005).

Woods et al. (2002) divided Garrard County into four ecoregions within the Interior Plateau Region based on geology, soils, and vegetation: Inner Bluegrass, Hills of the Bluegrass, Outer Bluegrass, and Knobs-Norman Uplands (Figure 1). The Inner Bluegrass is underlain by Middle Ordovician limestone of the Lexington Formation. The Hills of the

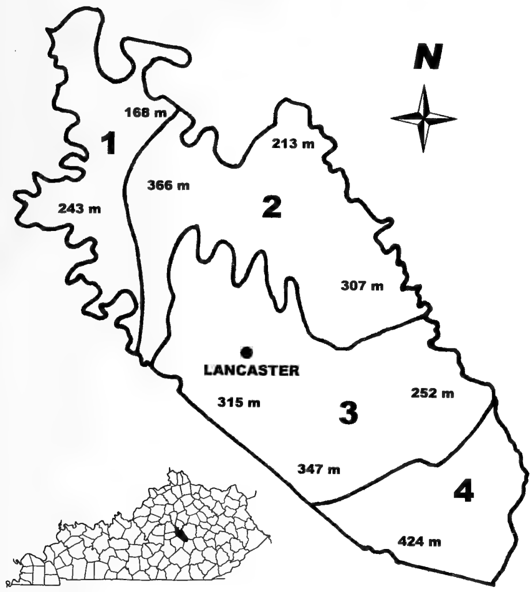

Figure 1. Garrard County, Kentucky, Ecoregions: (1) Inner Bluegrass, (2) Hills of the Bluegrass, (3) Outer Bluegrass, (4) Knobs-Norman Uplands (Woods et al. 2002).

Bluegrass are composed of Upper Ordovician calcareous siltstone and shale of the Garrard and Clays Ferry Formations. The Outer Bluegrass is underlain by Upper Ordovician limestone and dolomite of the Ashlock and Drakes Formations. The Knobs-Norman Uplands are comprised of Middle Silurian Crab Orchard shale and Brassfield dolomite, Middle Devonian New Albany shale and Boyle dolomite, and Lower Mississippian siltstone of the Wildie, Nada, Halls Gap, Cowbell, and Nancy Members and New Province shale Member of the Borden Formation (McDowell et al. 1981). Elevation ranges from 157 m in the northern part near the Kentucky River across from Jessamine County to 424 m in the southern part adjacent to Rockcastle County (Figure 1).

Major soil associations in the Inner Bluegrass are Maury-Hampshire-Loradale soil series, Hills of the Bluegrass belong to the Eden-Nicholson-Lowell soil series, Outer Bluegrass is Lowell-Shelbyville-Fairmont soil series, and the Knobs-Norman Uplands belong to the Colyer-Rockcastle-Otway soil series (Bailey and Winsor 1964). These soils are derived from the lithological parent materials within each ecoregion.

Braun (1950) classified the vegetation of the Kentucky Interior Plateau as belonging to the Western Mesophytic Forest Region, a mosaic of mixed *Quercus-Carya* and mixed mesophytic forests. Küchler (1964) classified the potential natural vegetation of this eastern deciduous region as *Quercus-Carya* forest. Natural upland communities are represented in the four ecoregions of Garrard County by a scattered mosaic of woodlands and forests. Much of the county is agricultural cropland and pastureland with *Festuca arundinacea* prevalent. The Inner Bluegrass is mainly *Quercus-Carya* on drier sites with *Quercus-Acer* on moister sites. The Hills of the Bluegrass are dominated by *Quercus-Carya* on drier sites and *Quercus-Fraxinus* on moister sites. The Outer Bluegrass includes *Juniperus-Robinia* and *Quercus-Carya* on drier sites, and mixed hardwoods on moister sites. The Knobs-Norman Uplands have *Quercus-Carya* on drier sites, *Quercus-Pinus* on drier sites, and mixed hardwoods on moister sites (Woods et al. 2002).

In central Kentucky, the climate is continental humid temperate, consisting of cool winters and warm summers, with precipitation spread throughout the year (Trewartha and Horn 1980). Climatological data, 1977–2000, are derived from Danville, Boyle County, ca. 16.0 km west of Lancaster (Kentucky Climate Center 2001). Mean annual temperature is 12.8°C, with the mean lowest temperature, −0.5°C, in January, and the mean highest temperature, 24.4°C, in July. The mean annual precipitation is 124.1 cm, with the lowest precipitation, 8.0 cm, in October and the highest precipitation, 12.6 cm, in March and May. At 0°C, the mean growing season is 200 days, with the median first fall occurrence of frost on 28 October and the last spring occurrence on 10 April (Kentucky Climate Center 2001).

METHODS AND MATERIALS

We conducted a survey of mistletoe host trees within Garrard County, Kentucky, from 3 Jan until 23 Jan 2004. We used a vehicle, binoculars, and a 1997 Garrard County highway map for reference and traveled all the paved and passable gravel roads within the county. Road mileage was recorded by odometer, and host trees were identified and tallied by species. All trees counted had visible signs of

Table 1. Host specificity of *Phoradendron leucarpum* in Garrard County, Kentucky.

Tree species	Total	Percentage
Juglans nigra L.	856	49.20
Prunus serotina Ehrh.	335	19.25
Ulmus americana L.	209	12.01
Robinia pseudoacacia L.	160	9.20
Fraxinus americana L.	83	4.77
Celtis occidentalis L.	37	2.13
Maclura pomifera (Raf.) Schneid.	18	1.03
Acer saccharinum L.	16	0.92
Gleditsia triacanthos L.	15	0.86
Acer saccharum Marsh.	6	0.34
Carya ovata (Mill.) K. Koch	4	0.23
Quercus muhlenbergii Engelm.	1	0.06
Total: 12	1740	100.00

mistletoe infestation, i.e., branch or trunk clumps, cankers, clusters, limb die-back, and swellings. Hemmerly (1989) was followed to derive a mistletoe occurrence factor value. This density factor is a reflection of the total number of infested trees per kilometer, and it represents both spatial distribution and relative abundance of host trees. Our mistletoe occurrence factor was determined for Garrard County by dividing the total number of infested trees by the total kilometers of roads traveled. We collected certain representative mistletoe specimens and their host tree winter twigs for vouchers of each tree species. Specimens were obtained by using a 12-m fiberglass extendable linesman pole with an attached hook. Mistletoe and twig specimens were mounted and deposited in the Berea College Herbarium (BEREA). Nomenclature for all tree species is from Gleason and Cronquist (1991).

RESULTS AND DISCUSSION

Phoradendron leucarpum was observed on 1740 trees from 12 host tree species in 8 families within Garrard County (Table 1). The predominant host tree species was *Juglans nigra* with 856 trees (49.20%), followed by *Prunus serotina* with 335 trees (19.25%), *Ulmus americana* with 209 trees (12.01%), and *Robinia pseudoacacia* with 160 trees (9.20%) (Table 1). *Juglans nigra* and *Prunus serotina* were the two most important host trees in two other surveys in central Kentucky (Thompson 1992; Thompson and Noe 2003). *Quercus muhlenbergii* was recorded for only the second time as a host tree in Kentucky. *Acer saccharum* and *Carya ovata* were reported for the third time as host trees in Kentucky. The occurrence value was 3.33 host trees per kilometer based on a total of 523 km traveled. This density value was less than the 4.35 host trees per kilometer recorded for contiguous Rockcastle County (Thompson and Noe 2003).

American mistletoe exhibits an aggregated or clumped spatial distribution pattern among its host trees. This aggregated spatial pattern is highly influenced by its life history of avian dispersal of mistletoe fruits from one host tree to other trees of the same species (Hemmerly et al. 1979; Sadler and Hemmerly 1984; Thompson and Noe 2003). The availability of tall, mature host trees in open, upland forest terrain, rather than lowland forest terrain or closed, upland forest terrain, is an important factor in mistletoe distribution and infestation (Thompson and Noe 2003). Small towns in Garrard County, i.e., Bryantville, Davistown, Lancaster, and Paint Lick, had a greater infestation of mistletoe than other upland terrain as a general rule, which is likely a consequence of urban allurement of avian vectors.

Mistletoe has a considerable host tree specificity in certain regions over others, which is related to physiography, geological substrates, soils, and existing vegetation (Panvini 1991; Reed and Reed 1951; Thompson and Noe 2003). The limestone Inner Bluegrass and Outer Bluegrass ecoregions accounted for a majority of the host trees. The Knobs-Norman Uplands were next in number of host trees, and the Hills of the Bluegrass had the least number. The unique host specificity of this hemiparasite probably includes several other factors, e.g., the genetic variation of American mistletoe (leading to ecotypes or genetic race distinctions) and the subsequent genetic diversity of host trees (Panvini 1991; Thompson and Noe 2003).

LITERATURE CITED

Bailey, H. H., and J. H. Winsor. 1964. Kentucky soils. Univ. Kentucky Agric. Exp. Sta. Misc. 308.

Braun, E. L. 1943. An annotated catalog of spermatophytes of Kentucky. John Swift & Co., Cincinnati, OH.

Braun, E. L. 1950. Deciduous forests of eastern North America. Hafner Press, New York, NY.

Gleason, H. A., and A. Cronquist. 1991. Manual of vas-

cular plants of northeastern United States and adjacent Canada, 2nd ed. New York Botanical Garden, Bronx, NY.

Hemmerly, T. E. 1989. Mistletoe parasitism in Tennessee. J. Tennessee Acad. Sci. 64:121–122.

Hemmerly, T. E., A. A. Forsythe, and M. L. Womack. 1979. Black gum—exclusive host of mistletoe in Lawrence County, Tennessee? J. Tennessee Acad. Sci 54: 89–90.

Hull, R. J., and O. A. Leonard. 1964a. Physiological aspects of parasitism in mistletoes (*Arceuthobium* and *Phoradendron*). I. The carbohydrate nutrition of mistletoe. Pl. Phys. 39:996–1007.

Hull, R. J., and O. A. Leonard. 1964b. Physiological aspects of parasitism in mistletoes (*Arceuthobium* and *Phoradendron*). II. The photosynthetic capacity of mistletoe. Pl. Phys. 39:1008–1017.

Kentucky Climate Center. 2001. The Kentucky Climate Center at Western Kentucky University Station Climate Summaries—Danville, Boyle County station. Accessed 12 Jan 2004 at: http://kyclim.wku.edu/cgi-bin/stations/152040.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. Map and accompanying manual. Am. Geogr. Soc. Spec. Publ. 36.

Kuijt, J. 2003. Monograph of *Phoradendron* (Viscaceae). Syst. Bot. Monogr. 66.

McDowell, R. C., G. J. Grabowski, Jr., and S. L. Moore. 1981. Geologic map of Kentucky. U.S. Geological Survey, Washington, D.C.

Panvini, A. D. 1991. The physiological ecology and population genetics of *Phoradendron leucarpum* (Raf.) Rev. & M. C. Johnston, a hemiparasitic mistletoe. Ph.D. dissertation, Vanderbilt Univ., Nashville, TN.

Reed, C. F., and P. G. Reed. 1951. Host distribution of mistletoe in Kentucky. Castanea 16:7–15.

Reveal, J. L., and M. C. Johnston. 1989. A new combination in *Phoradendron* (Viscaceae). Taxon 38:107–108.

Sadler, K. C., and T. E. Hemmerly. 1984. American mistletoe (*Phoradendron serotinum*) in the northeastern central basin and adjacent dissected highland rim of middle Tennessee. J. Tennessee Acad. Sci. 59:42–46.

Scharpf, R. F., and F. G. Hawksworth. 1974. Mistletoes on hardwoods in the United States. U.S.D.A., Forest Serv., Forest Insect & Disease Leafl. 147.

Thompson, R. L. 1992. Host occurrence of *Phoradendron leucarpum* in the Lexington-Blue Grass Army Depot, Blue Grass Facility, Madison County, Kentucky. Trans. Kentucky Acad. Sci. 53:170–171.

Thompson, R. L., and F. D. Noe, Jr. 2003. American mistletoe (*Phoradendron leucarpum,* Viscaceae) in Rockcastle County, Kentucky. J. Kentucky Acad. Sci. 64:29–35.

Trewartha, G. T., and L. H. Horn. 1980. An introduction to climate, 5th ed. McGraw-Hill Book Co., New York, NY.

Wikipedia, the free encyclopedia. 2005. Garrard County, Kentucky. Accessed 9 Dec 2004 at: http://en.wikipedia.org/wiki/Garrard_County_Kentucky.

Woods, A. J., J. M. Omernik, W. H. Martin, G. J. Pond, W. M. Andrews, S. M. Call, J. A. Comstock, and D. D. Taylor. 2002. Ecoregions of Kentucky (color poster with map [map scale 1:000,000], descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, VA.

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Johan Linder (Lindestolpe) (1676–1724), Eponym of the Generic Name *Lindera* Thunberg (Plantae: Lauraceae)

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ABSTRACT

Johan Linder (1676–1724), Swedish botanist and physician, is the eponym of the plant generic name *Lindera* (Lauraceae), dedicated to him in 1783 by Carl Peter Thunberg. The present account of Linder includes biographical data, comments on his position in the development of Swedish floristic botany, and discussion of his best-known botanical work, *Flora Wiksbergensis* (1716), the fourth printed account of Swedish local flora.

INTRODUCTION

The genus *Lindera* was described by the Swedish botanist Karl Peter Thunberg (Thunberg 1783) for a species of far eastern Asia. In the original place of publication, the source of the name is not explained, but later, in his *Flora japonica,* Thunberg (1784) dedicated the genus to "Dn. Linder," a Swedish botanist and physician who preceded him, as follows:

> "*Nomen* dedi huic in memoriam Dn. Linder, postea Lindestolpe, Medic. et Botanic. suo tempore celebris in Svecia, et Florae Wiksbergensis Auctoris."

> ["Name dedicated to the memory of Dn. [Johan] Linder, later Lindestolpe, doctor and botanist, celebrated in his time in Sweden and author of Flora Wiksbergensis."]

We cannot say why Thunberg chose to memorialize a Swede in the name of a genus then known only from eastern Asia. No connection between Linder and that part of the world has come to our notice. We suggest that because other genera had been named for Thunberg's European predecessors—a select group among whom eponymized non-Swedish botanists outnumbered the Swedes—he simply chose to add another of his countrymen to the list.

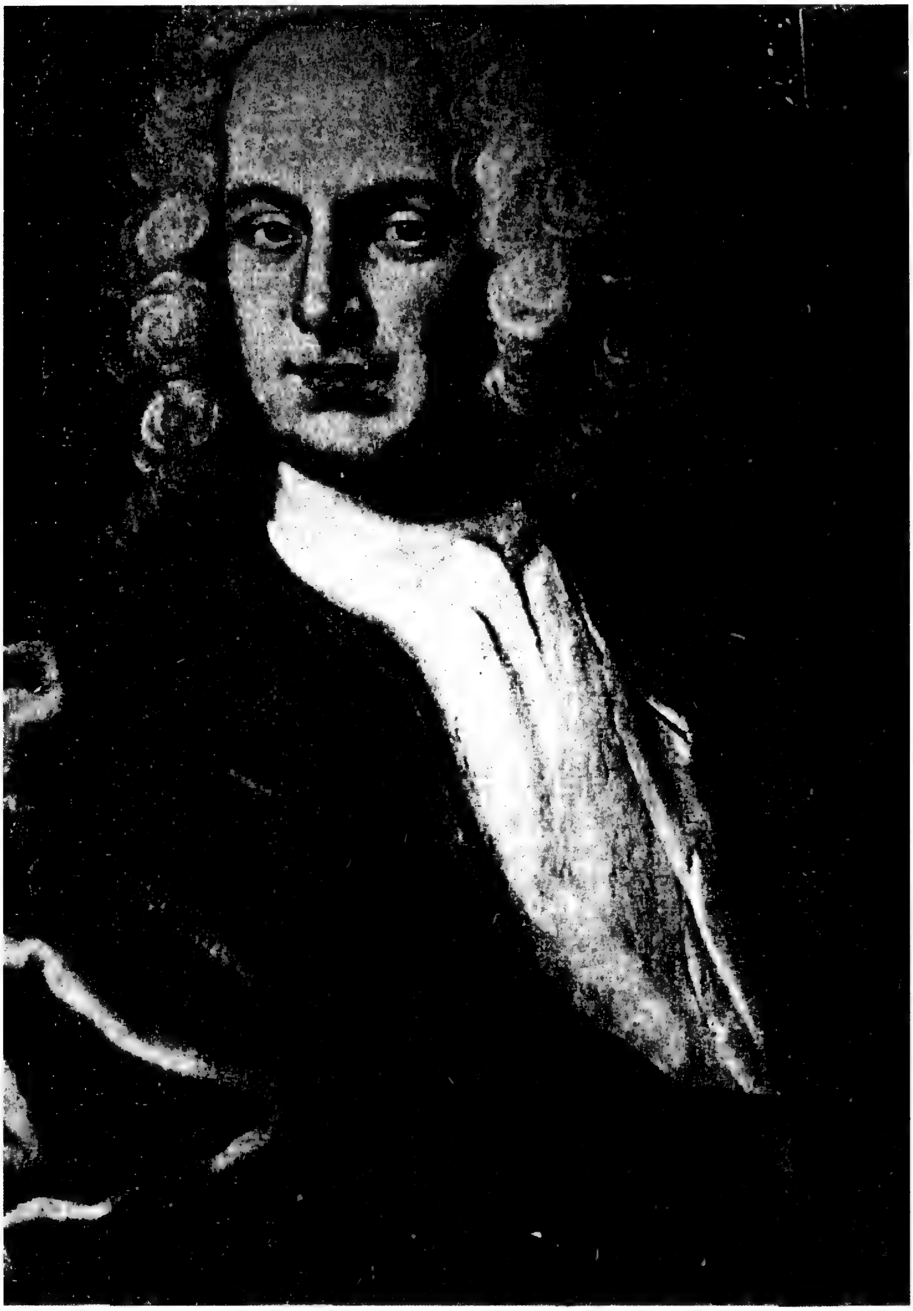
Lindera now encompasses ca. 100 species, three of which are North American, the rest eastern Asian. The most common North America species, spicebush (*Lindera benzoin*), is an easily recognized shrub or small tree found in forests over much of eastern United States.

We became interested in Johan Linder after one of our students elected to do a paper on spicebush and asked us about the dedicatee. Knowing little about Linder (Figure 1), we decided to learn more; this paper is the result. Our initial searching for information on Linder—we used the term "linder"—yielded almost nothing, but later, when we used the term "lindestolpe," his post-enoblement name, we found more data.

LINDER'S LIFE

The biographical data in some accounts of Linder are at best skeletal and sometimes contradictory (e.g., Quattrochi 2000; Sprengel 1808; Winckler 1854; Wittstein 1856). Sachs's (1906) *History of botany (1530–1860)* does not mention him. And, most surprising of all, Linder is not even represented in Fries's (1950) *A short history of botany in Sweden.* In contrast, other such works are excellent sources of data on him (e.g., Clemedson 1972; Eriksson 1969; Fries 1909; Wikland 1980–1981). The English-language accounts of Linder we have seen are terse in the extreme, citing birth/death dates and sometimes mentioning *Flora Wiksbergensis.* The biographical account of Linder below is based mostly upon Clemedson (1972).

Johan Linder was born in Karlstad, Sweden, in 1676. His father, Johan Lind, was a coast guard officer. Linder began his schooling in his hometown, continuing his education first in Åbo (present-day Finnish city of Turku, which in Linder's time was part of Sweden) where he took his diploma in 1700. Thereafter, he pursued his undergraduate studies in Uppsala, Sweden, until 1703. In Åbo, inspired by Professor Johan Gottschalk Wallerius, he developed an interest in medical research. On 17 May 1702 Linder defended his thesis, *De*



Johan Linder
Oljemålning av J. H. Scheffel
Tillhör Socialstyrelsens porträttsamling

Figure 1. Johan Linder (1676–1724). Portrait by J. H. Scheffel in the collection of the Swedish National Board of Health and Welfare (Socialstyrelsen), Stockholm. Reproduced from Clemedson (1972).

pomis hesperidum ("On the Apple of the Hesperides"), with Professor T. Rudeens as the presiding thesis chairman. While in Uppsala, Linder held a royal scholarship from the crown and worked under the guidance of Olof Rudbeck the Younger. He was also active in the University Council during this time. In 1705, he defended a thesis, *De foeda lue venerea dicta,* with Professor Lars Robergs as the presiding thesis chairman. It was not until 1713 that this thesis was translated into Linder's native Swedish under the title of *Tankar om then smittosamma sjukdom franzoser* ("Thoughts about the very infectious French disease [syphilis]"). This was the first detailed account of this venereal disease in Swedish history. In 1706 Linder received a stipend from the royal family to study abroad for his doctor of medicine; this level of education was not yet available in Sweden. For these studies, he traveled to the little town of Harderwijk, Netherlands, where there was a university with medical school faculty. The university itself was in existence from 1648 to 1811, and the medical faculty was supported between 1700 and 1735. In addition to Linder, twenty-some Swedes completed their medical studies at Harderwijk then. Among these were Carl Linnaeus's teacher in Växjö, Johan Stensson Rothman (in 1713); Nils Rosén (in 1730), later ennobled to Rosenstein and professor and colleague of Linnaeus in Uppsala; and even Carl Linnaeus himself (in 1735), later ennobled to von Linné. Linder received his medical degree in 1706 and continued with additional studies over the next year in Leyden (Leiden), Netherlands.

In 1708, Linder returned to Sweden where he held several medical appointments including service to the Royal Navy in the Gulf of Finland and as a doctor at Viksberg, a health spa. Eventually, he opened his own practice in Stockholm. In 1719, he was appointed as a member of the Medical College, and in that same year was ennobled with the name of Lindestolpe.

Linder was first married to Anna Öhrner and later, in 1720, to Eva Christina Cronhielm. He died on 24 Mar 1724 in Stockholm. His death ended his family line. (Some sources give 1723 as the date of his death. We follow the several Swedish accounts that give 1724.)

The historian Johan Fredrick Sacklén, in his 1822 biographical work *Sveriges läkare-historia* ("Sweden's History of Medical Doctors"), described Johan Linder as highly respected, good at Latin and at Swedish prose, and a learned and skilled doctor (Clemedson 1972).

FLORA WIKSBERGENSIS

Viksberg is located in Salem Municipality in Stockholm County, Sweden, about 30 km southwest of Stockholm. In the early 18th century, it was the estate of one Anders Ehrenfelt, who was the commissioner/superintendent of the Riksens Ständers Banco. It had a desirably located and popular health spa/spring. The grounds boasted a beautiful meadow bordered by many large oak trees on one side and by the "Korperberget," a large hill, with rock outcrops, on the other side. A mixed woodland was located at the base of the Korperberget; close by was a large lake, Mälaren, from which a cove extended into the estate. Long considered of botanical interest, the Salem area has been the site of various botanical field trips, such as those by the Svenska Botaniska Föreningen (Clemedson 1972; Froman 1931; Halden 1950; Segerström 1918; Wikland 1980–1981).

Linder's *Flora Wiksbergensis,* first published in 1716 (second edition 1728), was the fourth printed account of Swedish local flora, each simply a listing of plants. It was preceded by Schroderus's list in *Enkomion Uplandiae,* published in 1633; Tillands's catalog of the Åbo flora, 1673; and Bromelius's catalog of the Gothenberg flora, 1694. In addition to Linder, two others of these four authors were later memorialized in generic names of plants: *Tillandsia* Linnaeus and *Bromelia* Linnaeus.

The full title of *Flora Wiksbergensis* as given on the title page of the work (Figure 2) is *Flora Wiksbergensis, eller Ett Register uppä the Träd / Buskar / Örter och Gräs / som innom en fierdings wäg kring Suurbrunnen Wiksberg, antingen på åkrar sås / eller Wildt wäxa / med theras brukeligaste namn på Latin och på Swensko.* We translate this as follows: "Flora Wiksbergensis, or a registry of the trees, shrubs, herbs, and grasses within walking distance of the Viksberg health spa/spring, in field or ridge or wild growth, with their names in Latin and in Swedish."

The flora (Figures 2, 3), an octavo book of

JOHAN LINDERS

FLORA WIKSBERGENSIS,

Eller

Ett Register uppå the Träd/ Buskar / Örter och Gräs/ som innom en fierdings wäg kring Suurbrunnen Wiksberg, antingen på Åkrar sås/ eller Wildt wexa / med theras brukeligaste namn på Latin och på Swenska.

STOCKHOLM/
Tryckt hoos Sal. J. G. MATTHIÆ, Kongl. Ant. Archivi Boktryckarens Enckia / Af JOH. L. S. HORN, Fact.
Åhr 1716.

Figure 2. Title page of Johan Linder's *Flora Wiksbergensis* (1716). Reproduced from Clemedson (1972).

A.

ABIES procera, ramis a radice caudicem prosequentibus, folio crassiore, cortice subrubro, Går-Graan.
Abies procera viminalis, ramis caudicem prosequentibus, reflexis, folio tenero, cortice subrubro, Graan med långe inbögde qwistar/ Tunnbindare-Graan.
Abies candida elatior, ramis rarioribus, folio tenui, cortice subcinereo, Myr-Graan/ Thanar-Graan.
Abies pyramidalis, ramis ad radicem crebris, fruticescens, Granbuske.
Absinthium, Mahlört.
Acer: Platanus, Lönn / Lönnträd.
Acetosa major, pratensis, Stor Engie-Syra.
Acetosa minor lanceolata, Berg-Syra med hwasse blad.
Acetosa minima, non lanceolata, Bergsyra/ med smale blad.
Aconitum bacciferum racemosum: Christophoriana, S. Christophers ört / Will-drufwa.
Adiantum aureum majus: Polytrichum majus,
A

Figure 3. Portion of original text (*Abies–Adiantum* [pars]) of Johan Linder's *Flora Wiksbergensis* (1716). Reproduced from Clemedson (1972).

iv + 42 pages, is a rare item; a copy of the 1716 edition was recently offered—and apparently sold—on the internet (Löwendahl Rare Books, London) for £500 (=$902.25 as of 15 Oct 2004).

Flora Wiksbergensis appeared in a 'new' version in 1972 (Clemedson 1972). In that work only two pages of the 1716 edition are given in facsimile: the title page and the first page of the plant list. The complete list of 545 species is in modernized/annotated format, with the entries in the order that Linder gave them. Each entry has the scientific and Swedish names as used by Linder. To most entries, the modern editor has added the currently accepted binomial and various pre-Linnean synonyms from Dodoens, Rivinus, Rudbeck, Scheuchzer, Tabernaemontanus, Tournefort, and others. A few of the entries represent variations of a single species, e.g., 3 for *Alnus glutinosa,* 10 for *Corylus avellana,* 4 for *Picea abies,* 4 for *Pinus sylvestris,* and 2 for *Tilia cordata.* Among the entries are algae, fungi, lichens, mosses, liverworts, lycosphens, and seed plants. In common with other pre-Linnean floristic productions, most of the names are polynomials, but some (ca. 20%) are binomials. (Not until Linnaeus's *Species plantarum* [1753] were binomials used consistently in a floristic work.) Some of the binomials in the flora are in use for the same species today, e.g., *Aquilegia vulgaris, Hyoscyamus niger,* and *Sorbus aucuparia.* Some are closely similar to current names, e.g., *Menthastrum arvense* (=*Mentha arvensis*). Others would be

inexplicable to current readers without further study, e.g., *Myrtus palustris* (=*Ledum palustre*) and *Trifolium aquaticum* (=*Menyanthes trifoliata*). Some of the polynomials are impressively prolix, e.g., *Geranium Robertianum montanum foliis incisis flore pleno purpureo pentapetalo* (=*Geranium robertianum*) and *Melilotus Sylvestris ramosus, flore albo globoso, foliis crenatis lanuginosis* (=*Melilotus alba*).

To see how often *Flora Wiksbergensis* is noted in Swedish floristic publications, we checked, in the Lloyd Library, Cincinnati, 60 such works published in the period 1755 to 1920. Linder's flora is cited in Linnaeus's *Flora Svecica* (1755) (under "Opera Svecica"); Nathorst (1903); and Nyman (1868), under "Svenska och andra skandinaviska botaniser e.a., hvilkas arbeten ellen upptäkter omtalas i denna bok." The work is missing from Wikstrom's comprehensive *Stockholms flora* (Wikstrom 1840). Nordstedt (1920) pointed out that six of Linder's plants are the first records of those species in the flora of Sweden: *Athyrium alpestre, Campanula latifolia, Crepis tectorum, Lathyrus palustris, Trifolium agrarium,* and *Vicia angustifolia.* Among the fungi, Lagerheim (1909) cited five names of fungi from *Flora Wiksbergensis,* suggesting modern names for but two of them: *Fungus juniperinus* (=*Gymnosporangium*) and *Ustilago secalina* (=*Tilletia secalis,* a questioned determination).

Linder's flora is cited in a few bibliographic works, e.g., Krok's *Bibliotheca botanica suecana* (1925); Linnaeus' *Bibliotheca botanica* (1736); Pritzel's *Thesaurus literaturae botanicae* (1972), and Sallander's *Bibliotheca Walleriana* (1955) but is missing from others in which one might reasonably expect it to be a part: Burdet's *Ouvrages botaniques anciens* (Burdet 1985); Hartman's *Handbok i skandinaviens flora* (Hartman 1820, 1849), both editions of which have many pages, small print, of literature citations; and Jackson's well-known *Guide to the literature of botany* (Jackson 1881).

LINDER'S OTHER PUBLICATIONS

Publications by Johan Linder cover a wide range of topics. In addition to his Viksberg opus, his writings include, among other subjects, the Apple of the Hesperides; the medicinal efficacy of spring (mineral) water; the French disease (syphilis), malaria and China bark (quinine bark), scurvy, and the occurrence of the Black Plague in northern Europe in 1711; parasites in the human body; scorpions; dyeing with Swedish plants; poisons, narcotics, tobacco, and opium; and love potions and sleep and dreams. Although we have found no complete bibliography of his works, listings of many of them can be found at the websites of the Swedish National Library (Kungliga Biblioteket: Libris webbsok); at WorldCat; and at Perbos Farmacihistoriska Sidor.

AFTERWORD

In company with the seldom consulted or cited floristic works of other pre-Linnean writers, *Flora Wiksbergensis* and its author, Johan Linder, are of little concern today except for their place in the early development of floristics in Sweden. But Linder's surname, memorialized in the genus *Lindera,* will last into the far future.

We close this account with Áskell Löve's 1953 tribute to the Pre-Linneans (Löve 2004).

> The common man's hobby often becomes the uncommon man's sole interest. For centuries, the man in the street in Sweden has been a lover and student of plant life. His children and his children's children profited by—and extended—his floristic knowledge. And so it is not surprising that, out of the ranks of the common folk of Sweden, came the earliest botanists, some of them recognized throughout the world as not only the first in time but also the first in rank. Their prominence is but the natural outgrowth of the nation's interest—a folk interest—in the field of botany.
>
> It has often been said that Linnaeus must have been the creator of the Swedish interest in plant life, since he published the first scientific flora of his country as early as 1745. But actually this was by no means the first scientific account of the plants of Sweden. Almost a century before the birth of Linnaeus, Swedish vegetation was investigated by real botanists, still unforgotten scientists like Frankenius, Tillands, Måsson, the two Rudbecks, Palmberg, Linder, Bromelius, Celsius, and others, [who] produced manuals good enough to infect the Swedish people with an interest in plants where, even then, every garden in this long country was a bit of Paradise to its owner. Even then, two hundred and fifty years ago, the Swedish landscape in all its variations, had already become the Garden of Eden to all who needed rest from the pressure of daily work.

ACKNOWLEDGMENTS

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LITERATURE CITED

Burdet, H. M. 1985. Ouvrages botaniques anciens. Conservatoire et Jardin Botaniques, Genève.

Clemedson, C.-J. (ed). 1972. Flora Wiksbergensis. Sörmländska Handlingar N:r 28. Gust. Österbergs Tryckeri, Nyköping, Sweden. [Transcription of 1716 edition.]

Eriksson, G. 1969. Botanikens historia i Sverige intill år 1800. Almquist & Wiksell, Uppsala.

Fries, R. E. 1950. A short history of botany in Sweden. Almqvist and Wiksell, Uppsala.

Fries, T. M. 1908. Bref och skrifvelser af och till Carl von Linné. Första afdelningen, del. II. Ljus, Stockholm.

Fröman, I. 1931. Föreningens varutflykt. Svensk. Bot. Tidskr. 25:284–287.

Halden, B. E. 1950. Korperberget vid Viksberg i Salem, Södermanland, jämte några ord om biotoperna för *Asplenium ruta-muraria* och hassel. Svensk Bot. Tidskr. 44:535–550.

Hartman, C. J. 1820. Handbok i Skandinaviens flora, innefattande sveriges och norriges Vexter, till och med Mossorna. Zacharias Haeggström, Stockholm.

Jackson, B. D. 1881. Guide to the literature of botany. Longmans, Green & Company, London.

Krok, T. O. B. N. 1925. Bibliotheca botanica suecana ab antiquissimis temporibus ad finem anni MCMXVIII. Almqvist $ wiksell, Stockholm.

Lagerheim, G. 1909. Verzeichnis von parasitischen Pilzen aus Södermanland und Bohuslän. Svensk Bot. Tidskr, 3: 18–40.

Linnaeus, C. 1736. Bibliotheca botanica. Salomonen Schouten, Amsterdam.

Linnaeus, C. 1753. Species plantarum. L. Salvii, Holmiae.

Linnaeus, C. 1755. Flora Svecica. Laurentii Salvii, Stockholmiae.

Löve, Á. 2004. Linnaeus and the Swedish flora. [Publication of a essay written in 1953.] http://www.ou.edu/cas/botany-micro/ben/ben291.html. Accessed 11 Oct 2004.

Nathorst, A. G. 1903, Svenska växtnamn. P.A. Norstedt & Söner, Stockholm.

Nordstedt, A. O. 1920. Prima loca plantarum suecicarum. Bot. Not. (Bilaga) 1920:i–iv, 1–95.

Nyman, C. F. 1868. Utkast till svenska växternas naturhistoria eller sveriges fanerogamer. Sednare delen. Abr. Bohlin, Örebro.

Pritzel, G. A. 1972. Thesaurus literaturae botanicae. Otto Koeltz, Koenigstein. [Reprint of a work first published in 1871–1877.]

Quattrocchi, U. 2000. CRC world dictionary of plant names. Volume 2. D–L. CRC Press, New York, NY.

Sachs, J. von. 1906. History of botany (1530–1860). Clarendon Press, Oxford.

Sallander, H. 1955. Bibliotheca Walleriana. Vol. 1. Almqvist & Wiksell, Stockholm.

Segerström, A. L. 1918. Vårutiflykten till Salem. Svensk Bot. Tidskr. 12:479–481.

Sprengel, C. 1808. Historia rei herbariae. Sumtibus Tabernae Librariae et Artium, Amstelodami.

Thunberg, C. P. 1783. Nova genera plantarum. J. Edman, Upsaliae.

Thunberg, C. P. 1784. Flora japonica. In bibliopolio I. G. Mülleriano, Leipzig.

Wikland, E. 1980–1981. Lindestolpe, Johan. Pages 416–419 in B. Boëthius (ed). Svenskt biografiskt lexicon. Band 23. A. Bonnier, Stockholm.

Wikstrom, J.E. 1840. Stockholms flora, eller korrt Beskrifning af de vid Stockholm i vildt tillsländ förekommande Växter. Förra Delen. P. A. Norstedt & Söner, Stockholm.

Winckler, E. 1854. Geschichte der Botanik. Literarische Anstalt, Frankfurt a.M.

Wittstein, G. C. 1856. Entymologisch-botanisches Handwörterbuch, 2nd ed. J. J. Palm and Ernst Enke, Erlangen.

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Assessing the Water Quality of Two Creeks in Western Kentucky and Adjacent Tennessee using Biodegradable Dissolved Organic Carbon Analyses

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ABSTRACT

Assessment and comparison of the water quality of an agricultural creek (Ledbetter) and an undisturbed creek (Panther) emptying into Kentucky Lake, Kentucky and adjacent Tennessee, were conducted in July 2003 using biodegradable dissolved organic carbon (BDOC) analyses. Terrestrial, gravel bar, and surface water samples were collected in sterile whirl-pak bags from the creeks and analyzed for dissolved organic carbon (DOC) and biodegradable dissolved organic carbon (BDOC) content. Aliquots of samples were filtered and inoculated with creek microbes. Initial and final analyses were done using Oceanography-International Total Organic Carbon Analyzer with Infrared detector. The results show that the average BDOC concentration in Panther Creek (1.17 mg/liter; DOC = 2.50 mg/liter) was similar to that in Ledbetter Creek (0.87 mg/liter; DOC = 2.23 mg/liter). No clear DOC or BDOC trends were evident between the two creeks or well types sampled. Although results of the current study show no clear DOC or BDOC trends between the two creeks, it is important to monitor these creeks on a continual basis to maintain the quality of drinking water treatment and distribution systems.

INTRODUCTION

Protection and maintenance of high quality freshwaters are fundamental to both the ecology of freshwaters and human use. The constituents of freshwater include dissolved organic matter (DOM), typically measured as dissolved organic carbon (DOC), in addition to other substances (Curtis and Adams 1995). Dissolved organic carbon is the most abundant form of reduced carbon in aquatic systems (Wetzel and Manny 1977). The DOC, usually in the form of biodegradable dissolved organic carbon (BDOC), is a major nutrient source for organisms living in freshwater, but DOC also causes difficult to control and expensive problems in water treatment systems (Nelson et al. 1993). The DOC, defined as the organic carbon passing through a 0.5 μm filter, thus includes significant colloidal fractions (Ciaio and McDiffett 1990).

The subsurface regions of gravel bars and the hyporheic zone are important transient storage areas where dissolved organic matter, nutrients, and contaminants may be retained for periods of time and transformed before re-entering the surface stream environment (Hendricks and Rice 2000). Microbial activity within these subsurface regions is important in mediating nutrient and carbon cycling (Hendricks and White 1995) and is potentially important in transforming contaminants (Hendricks and Rice 2000).

Although freshwater is highly variable in its chemical composition, and rivers and streams more so than lakes, the biological importance of such variation is only evident at the extremes, and where human pollutants are substantial (Allan 1995). Factors such as agricultural runoff chemicals can influence the composition of bodies of freshwater. Physical characteristics of surface water such as the level of dissolved oxygen, which can affect water quality in terms of domestic and industrial uses, can also negatively affect aquatic life (Brooks et al. 2003). High levels of organic waste can reduce oxygen concentrations below life-sustaining levels and elevate carbon dioxide to many times atmospheric pCO_2 (Allan 1995).

Sources of DOC in streams and creeks are mainly allochthonous with little or no autochthonous contribution (Baron et al. 1991). Typical concentration of DOC in running freshwaters has a worldwide average of 5.8 mg/liter^{-1} (Nelson et al. 1993). Numerous abiotic and biotic processes are involved in the transformation of DOC within lotic ecosystems, categorized into humic and nonhumic substances that consist of compounds synthesized

biologically and chemically from degradation products, and of microorganisms and their decomposing remains (Wetzel 1983). Simple sugars, leachate from freshly shed leaves, exudates from periphyton blooms, and low molecular weight compounds are DOC sources that are taken up most rapidly (Allan 1995). Humic substances are of higher molecular weights, and are formed largely as a result of microbial activity on plant and animal material. They can also be polymerized abiotically resulting in compounds that are relatively resistant to further microbial degradation and thus recalcitrant (Wetzel 1983).

A water quality standard refers to the physical, chemical, and biological characteristics of water in relation to a specified use. To continue to have usable water, it is particularly essential to prevent the degradation of water quality characteristics (pollution) due to human activity. The DOC can be removed by flocculation, microbial degradation, and photolysis, with individual processes probably removing different portions of the total DOC pool (Curtis and Adams 1995). Much of the research on DOC dynamics in streams has focused on patterns of DOC in relation to seasonal variations (Tate and Meyer 1983). Biodegradable dissolved organic carbon rather than DOC is the actual signal to which growth and activity of heterotrophic microorganisms respond in natural waters, and its knowledge is required for modeling bacterial activity in aquatic ecosystems and avoiding bacterial regrowth and associated problems within drinking water treatment and distribution networks (Servais et al. 1987).

The purpose of my study was to assess and compare the water quality of two creeks, an agricultural creek and an undisturbed creek, emptying into Kentucky Lake, Kentucky and adjacent Tennessee, U.S.A., using biodegradable dissolved organic carbon analyses.

SITE DESCRIPTION

The two creeks sampled empty, on opposite sides, into the lower one third of Kentucky Lake (Figure 1), which is located in the western part of Kentucky and adjacent Tennessee, U.S.A. Ledbetter Creek (L), an "agricultural" creek, is on the west side of Kentucky Lake and empties into the "Kentucky side" of the lake. Panther Creek (P), an undisturbed creek, is on the east side in Land-Between-the-Lakes (LBL) and empties into Kentucky Lake from the "Tennessee side." Both basins are comprised of spring-fed, first order streams and are third order at the point where they enter Kentucky Lake.

Both streams have similar basin areas and discharge at base flow, and both have similar slopes, soil compositions, and streambed characteristics (sandy gravel in all reaches). The Panther Creek basin is more than 95% mature second-growth oak-hickory forest with small patches of grassland. The Ledbetter Creek basin is about 55% second-growth oak-hickory forest in various stages of succession and about 45% agriculture-urban areas with about 30 houses. Primary agricultural crops are corn, soybeans, and winter wheat.

EXPERIMENTAL METHODS

In July 2003, water samples, each ca. 200 ml, were collected from terrestrial, gravel bar, and surface water in sterile whirl-pak bags from Ledbetter and Panther creeks. There were two terrestrial wells (P-Wells 2 and 5) from Panther Creek and one terrestrial well (L-Well 14) from Ledbetter Creek; two gravel-bar wells (P-Wells 1 and 3) from Panther Creek and three gravel-bar wells (L-Wells 1, 2, and 3) from Ledbetter Creek; and two surface water (P-Surface Water and P-Spring Water) from Panther Creek and one surface water (L-Surface Water) from Ledbetter Creek. Samples collected were from capped and uncapped wells. However, the analyzed values from the uncapped well were not included in the average calculation of DOC and BDOC due to high concentrations of debris in the well. One sample was collected per well. Groundwater samples were from terrestrial wells around the margins of the creeks. Piezometer (PZ) well samples were taken from gravel bars around the creeks. Terrestrial well water was sampled by hand using a syringe and connector tube. Gravel bar water was sampled by hand from piezometer wells using a syringe and connector tube. Surface water samples were collected from the center of the creeks. Both the Panther Creek study site and the Ledbetter Creek study site were about 500 meters upstream. All samples were transported in a lightproof container at ca. 30°C.

Within 6 hours of collection about 200 ml

Figure 1. Map of the lower third of Kentucky Lake, western Kentucky/Tennessee (upper), showing locations of the Ledbetter Creek and Panther Creek basins. Inset map (lower) is of western Kentucky/Tennessee showing locations of study sites.

of each sample was filtered using pre-combusted 0.2 μm filters and poured into two sets of pre-baked 40 ml EPA vials. All the samples were then inoculated with creek microbes, obtained from unfiltered surface water from each creek. Half of the samples were immediately analyzed for dissolved organic carbon using Oceanography-International Total Organic Carbon Analyzer with Infrared detector. The remaining samples were incubated in the

dark and at about 25°C for 28 days and analyzed for biodegradable dissolved organic carbon using Oceanography-International Total Organic Carbon Analyzer with Infrared detector. A distilled water blank was used to calculate the corrected BDOC value by subtracting the distilled water reading (0.181) from the BDOC value obtained.

Taking the DOC and BDOC in a filtered sample and converting it to carbon dioxide (CO_2) measured the concentration of DOC and BDOC in all samples. After the sample has been acidified and purged of total inorganic carbon, sodium persulfate, a strong oxidizer, is added. This oxidant quickly reacts with organic carbon in the sample at 100°C to form carbon dioxide. Zero grade nitrogen gas serves as the purge gas and the carrier. Once the oxidation reaction is complete, the carbon dioxide is purged from the solution, concentrated by trapping, then desorbed and carried into a non-dispersive infrared analyzer (NDIR), which has been calibrated to directly display the mass of carbon dioxide detected. The mass of CO_2 is proportional to the mass of the TOC in the sample. Concentration of TOC is calculated by dividing the CO_2 mass by the sample volume.

The uncapped well (L-Well 1) was filled with leaves in various degrees of decomposition. This might explain the significantly higher levels of DOC and BDOC values reported for L-Well 1 as compared to the other wells. For this reason the results obtained for L-Well 1 were discarded.

RESULTS AND DISCUSSION

This investigation was conducted in July 2003. It is a preliminary study and so its results should be viewed in that light. Data (Table 1) analysis (Table 2) was conducted using Microsoft Excel and SPSS Version 11.0. The processed data show the average BDOC concentration in Panther Creek (1.17 mg/liter; DOC = 2.50 mg/liter) to be similar to that in Ledbetter Creek (0.87 mg/liter; DOC = 2.23 mg/liter). This pattern was different from that previously reported by Nelson et al. (1993), in a study conducted in the summer but at a different study site, where the DOC concentration in one creek (Redwater Creek, 32.0 mg/liter) was much greater than that in the other creek (Clearwater Creek, 3.8 mg/liter). Nelson et al. (1993) discovered that while climate, topography, vegetation, and land use were similar between the creeks, the soils were different, and the adsorption capacities of the soils were responsible for differences in DOC concentrations of the creeks.

The disaggregated data represented in Figure 2 show no clear DOC or BDOC spikes between the two creeks or well types sampled. The uncapped well (L-Well 1) was filled with leaves in various degrees of decomposition, which might explain the significantly higher levels of DOC and BDOC reported. For this reason, L-Well 1 was not factored into the evaluation of DOC and BDOC between the two creeks. The agricultural nature of Ledbetter Creek would have pointed to higher DOC values. However, due to the one time nature of the sampling and the small number of samples analyzed, no concrete conclusion can be made about the significant difference in concentrations of DOC and BDOC in the two creeks. Although agricultural runoffs may serve as an additional source of total DOC, in the summer because of low flow conditions and high retention times, bacteria are allowed to accumulate and metabolic processing of DOC by bacteria removes significant amounts of DOC (Ciaio and McDiffett 1990).

Sources in the watershed and removal mechanisms dictate the concentration of dissolved organic matter in water over time, and while removal mechanisms can include physical, geochemical and biological processes, they are dominated by physical processes (Baron et al. 1991). For Ledbetter and Panther creeks possible significant sources of DOC include leaf and litter inputs from terrestrial vegetation, and for Ledbetter also agricultural runoffs. Settling and burial in sediments, microbial consumption, and flushing downstream are possible ways by which DOC and POC can be lost in a stream (Baron et al. 1991).

The results of this study represent examples of data that might be obtained in more expansive investigations of these two aquatic ecosystems. Servais et al. (1987) showed that BDOC rather than DOC is the growth and activity signal to which heterotrophic microorganisms respond in natural waters. The knowledge of BDOC is, therefore, essential for modeling bacterial activity in aquatic eco-

Table 1. Average DOC and BDOC values for Ledbetter and Panther creeks. One sample per well was analyzed in duplicate. (DOC_i stands for initial DOC; DOC_f stands for final DOC.) Values represent samples taken from capped wells, piezometer wells, and one uncapped well. The value from L-Well 1 was not included in the average calculation of values.

Ledbetter (L) and Panther (P) Creeks Blank = 0.181	DOC_i (mg/L)	DOC_f (mg/L)	DOC_i - DOC_f = BDOC (mg/L)	Corrected BDOC (mg/L)
P-Well 1 – Gravel bar	2.431	2.784	- 0.353	0.000
P-Well 2 –Terrestrial	3.491	2.267	1.224	1.043
P-Well 3 – Gravel bar	2.228	0.939	1.289	1.108
P-Well 5 – Terrestrial	2.030	0.821	1.209	1.028
P-Surface Water	1.779	0.775	1.004	0.823
P-Spring Water	2.951	0.921	2.030	1.849
L-PZ 1 26 meters	2.602	1.089	1.513	1.332
L-PZ 2 33 meters	2.265	1.256	1.009	0.828
L-PZ 3 40 meters	1.681	1.098	0.583	0.402
L-Well 1– Gravel Bar (No Cap)	21.128	11.170	9.958	9.777
L-Well 2 – Gravel bar	2.495	1.049	1.446	1.265
L-Well 3 – Gravel bar	1.760	0.773	0.987	0.806
L-Well 14: Terrestrial	2.333	1.507	0.826	0.645
L-Surface Water	2.324	1.379	0.945	0.764

systems and avoiding bacterial regrowth and other associated problems within drinking water treatment and distribution systems. The method of water quality analysis employed here is used in Europe to monitor drinking water systems and has been proven to be an effective way of assessing water quality.

CONCLUSION

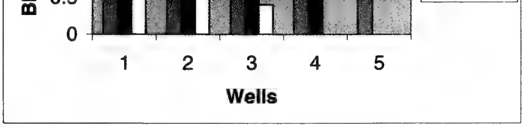
The measure of BDOC has been used mainly to evaluate the quality of raw and finished waters and to judge the performance of water treatment plants. The results of the current study show no clear DOC or BDOC trends between the creeks. However, it is important to monitor these creeks on a continual basis to maintain the quality of drinking water treatment and distribution systems. Human influences have a greater effect on the biosphere than natural changes, in both rate and magnitude. Human activities such as agriculture have transformed areas through which

Table 2. Corrected BDOC values for Ledbetter and Panther creeks. Values represent capped well samples and piezometer well samples.

	P – Corrected BDOC Values	L – Corrected BDOC Values	L – Piezometer Well BDOC Values	
	1.043	**1.265**	**1.332**	
	1.108	**0.806**	**0.828**	
	1.028	**0.645**	**0.402**	
	0.823	**0.764**		
	1.849			
Mean	1.170	0.870	0.854	
Standard Deviation	0.394	0.272	0.466	
Low (95%)	0.398	0.337	-0.058	
High (95%)	1.943	1.403	1.766	

streams and rivers flow and have increased the amounts of chemicals that enter streams and rivers. This is posing a greater threat to water resources.

Bacteria that pose a public health threat through their potential regrowth in water distribution systems derive their energy and carbon for growth from biodegradable dissolved organic carbon. BDOC should be removed in plants to limit bacterial regrowth. This will also minimize the quantities of disinfection by-product residuals in drinking water. Many running waters are in some need of both restoration and preservation. Protection of freshwaters is clearly warranted, and biological monitoring of the integrity of streams, rivers, and lakes will, hopefully, provide the data that makes the protection possible.



Series 1: Panther Well BDOC Values.

Series 2: Ledbetter Well BDOC Values.

Series 3: Ledbetter Piezometer Well BDOC Values.

Figure 2. Disaggregated BDOC values for Ledbetter and Panther creeks in Kentucky. Values represent capped well and piezometer well samples. The numbering is sequential: 1 = P-Well 2, L-Well 2, L-PZ 1; 2 = P-Well 3, L-Well 3, L-PZ 2; 3 = P-Well 5, L-Well 14, L-PZ 3; 4 = P-Surface water, L-Surface water; 5 = P-Spring water. Series 1—Panther well BDOC values; Series 2—Ledbetter well BDOC values; Series 3—Ledbetter piezometer well BDOC values.

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LITERATURE CITED

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Baron, J., D. McKnight, and A. S. Denning. 1991. Sources of dissolved and particulate organic material in loch vale watershed, Rocky Mountain National Park, Colorado, USA. Biogeochemistry 15:89–110.

Brooks, K. N., P. F. Ffolliott, H. M. Gregersen, and L. F. DeBano. 2003. Hydrology and the management of watersheds, 3rd ed. Blackwell Publishing, Ames, IA.

Ciaio, C. J., and W. F. McDiffett. 1990. Dissolved organic carbon dynamics in a small stream. J. Freshwater Ecol. 5:383–390.

Curtis, P. J., and H. E. Adams. 1995. Dissolved organic matter quantity and quality from freshwater and saltwater lakes in east-central Alberta. Biogeochemistry 30: 59–76.

Hendricks, S. P., and G. L. Rice. 2000. Utilization of a specially designed sediment colonization chamber to examine hyporheic water chemistry and microbial communities. J. Freshwater Ecol. 15:445–454.

Hendricks, S. P., and D. S. White. 1995. Seasonal biogeochemical patterns in surface water, subsurface hyporheic, and riparian groundwater in a temperate stream ecosystem. Arch. Hydrobiol 134:459–490.

Nelson, P. N., J. A. Baldock, and J. M. Oades. 1993. Concentration and composition of dissolved organic carbon in streams in relation to catchment soil properties. Biogeochemistry 19:27–50.

Servais, P., G. Billen, and M. C. Hascoet. 1987. Determination of the biodegradable fraction of dissolved organic matter in waters. Water Resources 21:445–450.

Tate, C. M., and J. L. Meyer. 1983. The influence of hydrologic conditions and successional state on dissolved organic carbon export from forested watersheds. Ecology 64:25–32.

Wetzel, R. G. 1983. Limnology, 2nd ed. Saunders College Publishing, Philadelphia, PA.

Wetzel, R. G., and B. A. Manny. 1977. Seasonal changes in particulate and dissolved organic carbon and nitrogen in a hardwater stream. Arch Hydrobiol. 80:20–39.

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Abstracts of Some Papers Presented at the 2004 Annual Meeting of the Kentucky Academy of Science

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AGRICULTURAL SCIENCES

Use of recycled waste as soil amendments: effects on dimethoate residues, broccoli yield and quality. CLARENCE E. JORDAN[1], MATTHEW A. PATTERSON, and GEORGE F. ANTONIOUS, Department of Plant and Soil Science, Kentucky State University, Frankfort, KY 40601.

Soil amendments derived from recycled solid waste materials can significantly reduce landfill disposal while improving soil nutrient levels and crop yield. The objectives of this study were to compare the effect of two recycled waste soil amendments on 1) spring and fall broccoli yield and 2) movement of the insecticide dimethoate into surface and groundwater. Recycled biosolids from the Nicholasville Wastewater Treatment Plant (Class A Biosolids) and composted yard and lawn trimmings from the KSU Research Farm (Yard Waste Compost) were applied to a Lowell silty loam soil at 50 ton/acre on a dry-weight basis. Six replicates of each soil amendment and 6 replicates of no mulch (NM) bare soil were planted with Packman F1 hybrid (spring) and Premium Crop (fall) broccoli seedlings (*Brassica oleracea* 'Aalsmeer') in rows of 2 m apart along the contour of the slope. Mature broccoli heads were weighed, head diameter, stalk diameter, and head infestation by cabbage looper (*Trichoplusia ni* Hubner) were recorded. Spring and fall broccoli yields from Class A Biosolid treatments (4600 and 2600 lbs/acre, respectively) and Yard Waste Compost treatments (3600 and 2400 lbs/acre, respectively) were significantly higher than yields from the NM treatments (2400 lbs/acre and 1800 lbs/acre, respectively). Broccoli head weight, head diameter, and stalk diameter also were significantly higher in amended vs. unamended treatments. Class A Biosolid and Yard Waste Compost amendments also significantly reduced cabbage looper infestation of broccoli heads and dimethoate residues in runoff and infiltration water relative to the NM treatment.

Natural products: new source of zingiberene and curcumene. DADDY N. BOATENG[1], GEORGE F. ANTONIOUS, Land-Grant Program, Department of Plant and Soil Science, and TEJINDER S. KOCHHAR, Department of Math and Sciences, Kentucky State University, Frankfort, KY 40601.

The use of the dried rhizomes of ginger plant, *Zingiber officinale* Roscoe (Zingiberaceae), as a medicinal agent and biorational source for antiviral and anticancer activity is well established. Ginger is a perennial plant that grows in India, China, Mexico and several other countries. Owing to the complexity of the active ingredients in their extracts, commercial synthesis is likely to be impractical. Composition of ginger oil prepared from fresh ginger rhizomes was determined by gas chromatography (GC) and GC-mass spectrometric techniques. The main sesquiterpene hydrocarbons identified were α-zingiberene (27–30%), α-curcumene (8–9%), β-sesquiphellandrene (4.8%), and bisabolene (3.2%). Analysis of purified hexane extracts prepared from the leaves of two wild tomato accessions of *Lycopersicon hirsutum* f. *typicum* Humb. & Bonpl. (PI-127826 and PI-127827) revealed the presence of α-zingiberene and α-curcumene. Mass spectrometric analysis of leaf extracts prepared from the two *L. hirsutum* f. *typicum* accessions and from fresh ginger rhizomes showed fragments with identical molecular ions at m/z 202 and at m/z 204, which are consistent with the assignment of the molecular formula of curcumene ($C_{15}H_{22}$) and zingiberene ($C_{15}H_{24}$), respectively, known as major constituents of ginger rhizomes. Analysis of the leaflets of PI-127826 and PI-127827 wiped with a cotton swab soaked with methanol indicated that methanol removed 90% of zingiberene and curcumene from the surface of the wiped leaves, indicating that these exudates are present on the leaf surface rather than in the leaf interior matrix. This research provides background information on the level of two sesquiterpene hydrocarbons in wild tomato species that can be grown locally using standard agricultural practices and may provide an opportunity for many farmers and organic growers who may be able to grow wild tomato foliage as alternative and biorational sources of zingiberene and curcumene and as medicinal agents for industrial use.

Half-lives of 2-tridecanone on vegetable leaves. GEORGE F. ANTONIOUS, Kentucky State University, Land Grant Program, Department of Plant and Soil Science, Frankfort, KY 40601-2355.

Concerns about pesticide safety usually involve two sides, the environment and the end-user. To protect the environment, the general trend is to use reduced levels of active ingredients. This trend creates a need for pesticide formulations with improved efficacy at low application rates. To protect the end-user, safe formulations that eliminate organic solvents are needed. Developing efficient natural products with low mammalian toxicity and little or no impact on environmental quality for use against vegetable insects that have gained resistance against many classes of insecticides is needed. 2-Tridecanone (hendecyl methylketone) was prepared from the leaves of five wild tomato accessions of *Lycopersicon hirsutum* f. *glabratum* Mull. (PI 126449, PI 134417, PI 134418, PI 251304, and

* presenter

[1] undergraduate student competitor

[2] graduate student competitor

LA 407) and used for spraying 45 day old pepper (*Capsicum annuum*), squash (*Cucurbita maxima*), radish (*Raphanus sativus*), tomato (*Lycopersicon esculentum*), broccoli (*Brassica oleracea*), Swiss chard (*Beta vulgaris*), and watermelon (*Citrullus lanatus*). No phytotoxicity was observed on the leaves following spraying with 2-tridecanone formulation. 2-Tridecanone in the wild tomato crude extract and on the leaves of the seven sprayed vegetables was identified and quantified using a GC/MSD. The initial deposits of 2-tridecanone were highest on pepper leaves and lowest on broccoli leaves. Decline of 2-tridecanone residues on the leaves as a function of time indicated that half-lives ($T_{1/2}$) values of 2-tridecanone ranged from 1.3 hrs on squash to 4.0 hrs on broccoli leaves. 2-Tridecanone has been shown to be a potent agent against a variety of insects and spider mites and could be a potential substitute for many synthetic pesticides used on vegetables.

Quality of squash grown with biosolids. ZACHARY M. RAY*, MATTHEW A. PATTERSON, and GEORGE F. ANTONIOUS, Kentucky State University, Land Grant Program, Department of Plant and Soil Science, 218-Atwood Research Facility, Frankfort, KY 40601.

Quality of summer squash is based on uniform shape, overall firmness, a glossy skin color, an intact well-trimmed stem portion, freedom from growth or handling defects such as discoloration and cuts or bruises. The use of biosolids as soil amendment provides not only a means for biosolids disposal, but can also improve soil fertility and physical properties of soils. Nutrients in biosolids are used to replace a supplement commercial fertilizer, while biosolids organic matter can improve crop yield and quality. The objective of this study was to compare summer squash quality and yields from three soil management practices: 1) biosolids (municipal sewage sludge) mixed with native soil at 30 t/acre, 2) biosolids mixed with yard waste compost at 1:1 ratio, and 3) rototilled bare soil used for comparison purposes. Field studies were conducted on a Lowell silty loam at Kentucky State University Research Farm, Franklin County, KY. Six replicates of each soil treatment were established in 18 plots of 22 $\times$ 3.7 m each. Seedlings of yellow squash, *Curcurbita pepo* (Conqueror III), were planted in rows 12 inches apart. Mature squash were harvested (15 harvests during the summer season) from each plot, weighed, and graded according to USDA standards for summer squash. Total harvest weight and weight and number of US Fancy, US #1, US #2, and Culls were obtained from each soil treatment. Biosolids mixed with yard waste compost produced significantly higher summer squash yield than controls. Our results have indicated that the methods of application of these two waste materials (biosolids and yard waste) are simple, inexpensive and energy conserving.

Will thinning of pawpaw fruit clusters increase fruit size and quality? KIRK W. POMPER* and SHERI B. CRABTREE, Land Grant Program, Kentucky State University, Atwood Research Facility, Frankfort, KY 40601-2355.

The North American pawpaw (*Asimina triloba*) is native to the eastern portion of the United States and has potential for use as a new tree fruit crop or in landscapes. Pawpaw fruit size not only varies among varieties, but among fruit within individual clusters; clusters range from 1 to 9 fruit. Fruit thinning is utilized with apples and peaches to increase fruit size, obtain uniform annual production, improve fruit quality, and avoid limb breakage. The objectives of this experiment were to determine if hand thinning of multi-fruit clusters to one fruit could be accomplished without causing abortion of the remaining fruit, and if average fruit size would be increased in thinned clusters. Four seedling trees (A3-7, A4-5, A5-2, and A5-12) 13 years old were subjected to within cluster thinning on 12 May 2004, when the average fruit length was 1.5 $\pm$ 0.4 cm (n = 40). On all trees, 15 clusters were hand thinned to one fruit per cluster and tagged; 15 additional control clusters were also tagged. The number of control and thinned clusters retained on the trees and the number of fruit per cluster was recorded on 20 May, 11 Jun, and 27 Jul 2004. Eight days after thinning, 79% of the control clusters were retained on the trees, while 66% of the thinned clusters were retained. At harvest, average fruit weight in thinned clusters was 73% and 26% greater than control clusters in trees A3-7 and A4-5. There is potential for hand thinning within clusters to increase average fruit size in pawpaw.

Analysis of paddlefish (*Polyodon spathula*) populations using microsatellite markers. JEREMIAH D. LOWE[2], STEVEN D. MIMS, KIRK W. POMPER, and BORIS GOMELSKY, Land Grant Program, Kentucky State University, Atwood Research Facility, Frankfort, KY 40601-2355.

Paddlefish (*Polyodon spathula*) is an ancient fish native to the Mississippi River system with economic potential from caviar and fillet products. Molecular markers could be useful tools for determining genetic diversity, sex identification, and in analysis of inheritance in paddlefish. Historically, intraspecies differences in paddlefish have appeared to be low when using other protein and DNA based marker systems. The objective of this study was to examine genetic diversity with the simple sequence repeat marker system with paddlefish accessions from Kentucky, Montana, North Dakota, Oklahoma, Louisiana, Alabama, and Missouri. DNA was extracted from fin clips using Promega's Wizard Genomic DNA Purification Kit. SSR primers were developed by Genetic Identification Services (Chatsworth, CA) using paddlefish DNA from Kentucky accessions. Eleven primers were screened that were developed especially for paddlefish. Product size ranged from 200 to 800 bp, and approximately 100 different products were amplified. Nearly all products amplified were polymorphic. Paddlefish populations from Ohio and Alabama had unique characteristics compared to other populations evaluated based on marker relationships.

Dose-dependent effects of salicylate on the plant-pathogenic fungus *Botrytis cinerea*. NORM STROBEL* and LARRY PORTER, Division of Biological Sciences and Nursing, Lexington Community College, Cooper Drive, Lexington, KY 40506.

Most research on the role of salicylate (SA) in plant-pathogen interactions has focused on SA-mediated activation of plant defenses. Total endogenous SA may increase to perhaps 10–100 M (locally) in infected plant tissues, whereas 2–10 mM SA is commonly applied for experimental enhancement of plant disease resistance. We hypothesized that SA might also be directly inhibitory to plant pathogens. Colony diameters of *Botrytis cinerea* (BC) on potato-dextrose agar (PDA) were unaffected by amendment with 0.2 mM SA, whereas 2–5 mM SA inhibited BC growth by ~50%, and 10–20 mM SA completely inhibited BC growth. In well-plate culture with a defined liquid medium, the dose-response pattern for inhibition of mycelial growth of BC was similar to that observed on PDA plates. In wells that initially contained 0.5–5 mM SA, BC eliminated both the UV-fluorescence of SA and the formation by SA of a purple chelate with added $Fe,^{3+}$ whereas an intense UV fluorescence and reaction with Fe^{3+} remained at 10 mM SA. Preliminary spectrophotometric determinations of SA with Fe^{3+} (A_{540}) also indicated the elimination by BC of 0.5–5 mM SA, but not 10 mM SA, within 2 days of inoculation of wells. We believe this to be the first report of SA metabolism by a plant-pathogenic fungus. Pathogen metabolism of SA could have important impacts on plant-pathogen interactions. SA and the pro-oxidant herbicide paraquat inhibited BC growth in a synergistic manner. This is consistent with the known ability of millimolar SA to inhibit several enzymes that protect cells from oxidative damage, and suggests a plausible mechanism for direct inhibition of BC by SA. We speculate that formulation with SA may enable reduced application rates for pro-oxidant fungicides, with activation of plant defenses by SA as an added benefit.

ANTHROPOLOGY AND SOCIOLOGY

Spatial analysis of Owens Farm. ADRIANNE SAMS[1], Department of Geosciences, Murray State University, Murray, KY 42071.

In 1996, Murray State's archaeological field school conducted a survey on Owens Farm in Ballard County, Kentucky, located in the Jackson Purchase area. The survey yielded ten prehistoric and historic sites, with two historic findings large enough for spatial analysis. In this paper the spatial distribution of historic artifacts in one of the two larger sites will be discussed. The comparison was completed on a grid system by mapping the artifact placement in accordance to their provenience. The first comparison was the distribution of architectural artifacts against the domestic artifacts. That comparison was then broken down into specialized analyses, comparing the placement of single artifact types. The results of the analysis provide a preliminary report on the spatial organization of the site.

Mining sites associated with the overseas Chinese in America and Australia. KRISTIN L. THOMAS[1], Department of Geosciences, Murray State University, Murray, KY 42071.

Over the past two decades, archaeologists of North America and Australia have begun to examine the culture and history of the overseas Chinese. Some of the earliest known Chinese immigrants to North America were located in the Land Between the Lakes of Western Kentucky. This paper compares the archaeology of Chinese mining sites in North America and Australia in an effort to set up a research design for the Chinese mining site in the Land Between the Lakes.

BOTANY AND MICROBIOLOGY

Relocation of the type locality of *Viburnum molle* Michaux, in Boyle County, Kentucky. TIMOTHY J. WECKMAN*, Department of Biological Sciences, Eastern Kentucky University, Richmond, KY 40475; JUDITH E. WECKMAN, Institutional Research and Assessment, Berea College, Berea, KY 40403; ROSE-MARIE ROESSLER, Biology Department, Centre College, Danville, KY 40422.

Viburnum molle was first described by André Michaux in 1803 from material he collected in Kentucky between 1793 and 1795. We wanted to know if the type locality could be established from the historical record, and, if so, if this threatened taxon still persists at the locality. We examined Michaux's travel journal, the original species description, and the type specimen of *Viburnum molle* in an effort to reestablish the type locality. Additional vouchers of *V. molle* collected in Kentucky from herbaria in the eastern United States were examined as was the historical record of collection efforts for this taxon. Likely sites where *V. molle* could have been collected were established and searches were conducted. Field efforts in 2003 in Boyle County, Kentucky, resulted in the discovery of an extant *V. molle* population from the presumed type locality.

CHEMISTRY

Spectroscopic properties of cyclophane/anthracene and cyclophane/9-fluorenone complexes in dichloromethane. AUGUSTINE AMONGE[1], MARK O'BRIEN, and THANDI BUTHELEZI, Department of Chemistry, Western Kentucky University, Bowling Green, KY 42101.

Interactions of host-guest on cyclophane-anthracene (C-A) and cyclophane-fluorenone (C-F) complexes in dichloromethane, where the cyclophane molecule is the host, are investigated. The stability constants, log (Ka), of C-A and C-F complexes are gotten via absorption and fluorescence spectroscopy. For the C-A System the measured log (Ka) is 4.2 + 0.2 from the absorption data at 325 nm and emission spectra at 382, 403 and 427 nm. The analogous measurement yielded 3.6 + 0.2 from absorption data at 309 nm and emission spectra at 304 and 604 nm from the C-F system. Heats of formation of these

complexes were determined by measuring complex association constants at 25, 29 and 32°C, using a temperature controlled Shimadzu UV-2101 PC spectrophotometer. Results indicate that binding of anthracene by this new cyclophane molecule is favored.

Host/guest interactions of cyclophane/anthracene and cyclophane/9-fluorenone complexes in dichloromethane. MARK O'BRIEN[2], AUGUSTINE AMONGE, and THANDI BUTHELEZI, Department of Chemistry, Western Kentucky University, Bowling Green, KY 42101.

Intermolecular forces play a vital role in the binding properties of host-guest systems. We have spectroscopically investigated the intermolecular interactions of a member of a new class of cycloclophane host molecules (Corrals). The host-guest interactions of corral 2/anthracene (C2/A) and corral 2/9-fluorenone (C2/F) complexes in dichloromethane were studied using absorption and emission data. The stability constants, log Ka, for the C2/A and C2/F complexes are determined. The stability constant for the C2/A system is 4.2 ± 0.2 as determined from absorption (at 325 nm) and emission (at 382, 403 and 427 nm) spectroscopic data. The C2/F system yields 3.6 ± 0.2 from absorption (at 309 nm) and emission (at 505 nm) spectroscopic data. Heats of formation for these complexes were determined by measuring the complex association constants at 25, 29 and 32°C. These results reveal that binding of the anthracene guest by this cyclophane molecule is thermodynamically favored over that for a 9-fluorenone guest. Excited state lifetimes of these systems are also determined. Theoretical and experimental studies of the vibrational energies of these systems are also investigated.

ECOLOGY AND ENVIRONMENTAL SCIENCE

Observations on the reproductive behavior of rare and endangered freshwater mussels (Bivalvia: Unionidae) from Kentucky. MONTE A. MCGREGOR*, ADAM C. SHEPARD, and THOMAS T. BARBOUR, Kentucky Department of Fish and Wildlife Resources, Frankfort, KY 40601.

Freshwater mussels are the most at-risk group of animals in North America. Of the 297 native mussel species in the United States, 71.7% are considered endangered, threatened, or of special concern, including 21 mussels that are endangered and presumed extinct. The state of Kentucky has one of the most diverse mussel populations in North America with 41 genera and 103 recognized species. The decline of mussel populations has led to recent advances in technology and proactive recovery of freshwater mussels. In 2002 the Kentucky Department of Fish and Wildlife's Wildlife Diversity Program developed the Center for Mollusk Conservation to aid in the recovery of rare and endangered mussels. As part of this continuing effort, we are currently holding 60 mussel species in semi-natural conditions in flow-through river tanks. We have observed several behavior types in captivity within the Lampsilinae, Amblemidae, and Anodontinae. These include the use of a super conglutinate fish-type lure (pheasant shell, *Actinonaias pectorosa*), worm-like lures (the endangered fanshell, *Cyprogenia stegaria* and the purple lilliput, *Toxolasma lividus*), several types of mantle flaps (*Lampsilis teres, L. cardium* and *L. fasciola*), and several conglutinate packets (*Pleurobema sintoxia, P. cordatum, Fusconaia flava, Ptychobranchus fasciolaris* and *P. subtentum*). Behavioral patterns were related to reason and temperature. Observations fit well to those described in the literature. Preliminary data suggests that conditions for survival and reproductive development are adequate in the semi-natural hatchery environment.

Nesting success, intraspecific brood parasitism, predation, competition, blood parasites and stress levels of wood ducks (*Aix sponsa*) in clustered and isolated nest boxes. AMELIA LEHMAN[2], Department of Biological Sciences, Murray State University, Murray, KY 42071.

Population decline of the wood duck (*Aix sponsa*) at the turn of the century sparked extensive population management attempts throughout the United States and Canada, including implementation of wood duck nest box monitoring programs. The objective of my study was to examine how nest box placement affects wood duck nesting success, and how hens are affected physiologically by box choice. I examined nesting success and efficiency, intraspecific brood parasitism, nest predation and competition, blood parasite occurrence, and stress levels of wood duck hens nesting in clustered and visually isolated nest boxes on Cross Creeks National Wildlife Refuge and Fort Campbell Military Reservation. My null hypothesis stated there is no difference in parameters between hens using clustered and isolated nest boxes. Hens in clustered and isolated boxes both had mean clutch sizes of 12 eggs, 83.3% and 85.7% nesting success, 85.3% and 81.3% efficiency, and blood glucose levels of 162 and 145 mg/dl, respectively. There were no significant differences in the length of bill, length of sternum, mass, or calculated condition index. There were also no significant differences in dump nesting and age between clustered and isolated boxes. Interspecific competition for nest boxes was significantly higher in isolated boxes. Blood corticosterone levels were significantly higher in hens nesting in isolated boxes. Based on my results, wildlife managers may enhance wood duck nesting and health by placing nest boxes within visual proximity of each other, rather than visually isolated.

Competition between ecto- and endo-types of mycorrhiza plays an important role in the regeneration of oaks on mesic sites in the central hardwood region of the eastern United States. PIERCE JOHNSON, JR., Department of Biological Sciences, Eastern Kentucky University, Richmond, KY 40475.

Oaks provide more native timber than any other hardwood, and acorns from oak forests are the most important wildlife food from deciduous forests. Fire disturbances were important in development of oak forests; however, since 1930, they have been suppressed. Potential oak re-

production (such as seedlings and sprouts) is being replaced by shade tolerant plants. Oak forests in the central hardwood region are likely to be replaced by less valuable hardwood forest species. Methods have been developed to correct this problem. The controlled burn method impacts shade tolerant plants more than oaks. The shelterwood method removes competing plants to provide more sunlight for shade intolerant oak seedlings. Due to the great diversity of oak species and site conditions, however, no single silvicultural method is likely to be successful. Mutualistic associations formed between plants and mycorrhizal fungi in a forest play a key role in nutrient and energy cycling. Mycorrhizal research in the eastern U.S. has been sparse. By contrast, research into interactions between mycorrhizal fungi and plants within Douglas fir forests in the west has been extensive and has provided valuable assistance in the maintenance and regeneration of these forests. Ectomycorrhizal fungi associated with oak trees are distinctly different from and compete with the arbuscular mycorrhiza and ericoid mycorrhiza associated with shade tolerant plants. This presentation compares the major types of plant-fungus associations in forests. Suggestions for research are provided that will lead to a fuller understanding of forest ecology in the central hardwood region and to a clearer understanding of why oak regeneration has become a problem.

GEOGRAPHY

Legal definitions of karst stormwater discharges. JOHN ALL, Western Kentucky University, Human Environment Linkages Program, Department of Geography and Geology, 1 Big Red Way, Bowling Green, KY 42101.

Bowling Green and other small municipalities have recently become subject to Clean Water Act (CWA) Phase II regulations for stormwater discharges. New management plans are being considered as these areas move into compliance. However, there is an important legal/hydrologic issue that has been overlooked which during later enforcement could penalize small karst municipalities. Generally, one of the simplest ways to manage stormwater is to force it to infiltrate into the ground. Infiltration will reduce the volume of water available to contribute to potential floods and soil will cleanse water of contaminants. However, injection wells (dry wells) are often used in karst and they do not have soil to absorb water and pollutants. Under the CWA, a 'point source' is a specific location (like a pipe) that directly contributes pollution into a river, lake or stream. An injection well in a karst landscape could thus be considered a point source subject to monitoring and regulation because of its direct connection to waterways via springs. If the EPA would adopt this definition, it would create major new requirements for karst municipalities. As stormwater options are considered by a multitude of smaller karst municipalities, this issue must be addressed early in the planning process or major costs could result later as additional infrastructure is required.

Dye tracing of groundwater through Russel Cave National Monument: Doran Cove, Alabama. BRIAN D. SAKOFSKY[2], NICHOLAS C. CRAWFORD, BENJAMIN TOBIN, and HEATHER VEERKAMP, Center For Cave and Karst Studies, Applied Research and Technology Program of Distinction, Department of Geography and Geology, Western Kentucky University, 1 Big Red Way, Bowling Green, KY 42101.

Cave explorers have scrutinized Doran Cove, an extensive watershed within the southern portion of Tennessee and northern Alabama, for years. The Cove has numerous caves, sinking streams, streambeds, and springs. The hydrologic relationship between these is not yet known. The primary objective of the research was to delimit the source area for the cave stream that flows through Russel Cave. A full karst hydrologic inventory was conducted for Doran Cove and dye receptors were placed at all springs and at several locations inside Russel Cave. Four dyes were injected into the spring-sinks along the Hartselle Formation-Monteagle Limestone contact. The preliminary results showed that all the dyes were transported by cave streams under Doran Cove, through Russel Cave to resurgence at Widows Spring. The continuing research is being funded by the National Park Service.

Representing geomorphic features in karst: accurately modeling cave resources. BENJAMIN TOBIN[2], JOHN ALL, NICK CRAWFORD, ANDY ZIMMERMAN, and BRIAN HAM, Western Kentucky University, Department of Geography and Geology, 1 Big Red Way, Bowling Green, KY 42101.

In recent years, resource management and urban planning have become prominent issues in our society. Both disciplines are concerned with managing human interaction with the environment. In order to properly manage any resource, an understanding of geographical relationships must be developed. In karst regions especially, this is a critical step in reducing human impact on the environment. Within a karst region it is difficult to correlate surface land features to subsurface features. It is possible, through a variety of interconnecting methods, to create spatially accurate portrayals of all geomorphic features within areas of such complicated land features. A combination of field methods and computer software has provided the high-resolution geographic data needed for this analysis. The use of cave radio and accurate GPS units provide increased accuracy in projecting cave maps onto surface maps. The cave itself is plotted and drawn on two computer programs using Adobe Illustrator and Compass. All of this information is then incorporated into a GIS using Cave Tools Extension. This creates a comprehensible and adaptable map that can be used as a basis for informed resource management and environmental planning.

HEALTH SCIENCES

A belated review of James A. Briggs. 1852. "Medical Topography and Diseases of Warren Co., Ky." Unpub-

lished M.D. dissertation, University of Nashville. 37 p., handwritten. JAMES X. CORGAN, Department of Geology and Geography, Austin Peay State University, Clarksville, TN 37044.

In the 1850s a dissertation was required for the degree of Doctor of Medicine, and the germ theory of disease had yet to develop. Concepts of the etiology of disease differed from modern norms. Briggs wrote on the health problems of the county where he lived. He felt that Warren County's seasonal illnesses were rooted in the landscape. Disturbances caused by building roads and channeling rivers might generate illness but were not major causes. Frequent fogs seemed strongly tied to bad health. Briggs compiled weather records and offered a guide to wise living. Like scores of medical dissertations that gather dust on library shelves this text casts light on the intellectual history of Kentucky.

Glutathione peroxidase activity in the erythrocytes from the blood of farm workers during the growing season. ADESUWA OSUNDE[1], AVINASH TOPE, FRED BEBE, and MYNA PANEMANGALORE, Nutrition and Health, Kentucky State University, Frankfort, KY 40601.

The exposure of farm workers to pesticides is increasing with time, which emphasizes the need to identify endpoints of exposure in the blood. In animal models, pesticides have been shown to produce oxidative stress. Glutathione peroxidase (GPX) is an enzyme found in cells that catalyzes the conversion of hydrogen peroxide to water, thereby preventing the accumulation of this toxic molecule as it can result in the development of oxidative stress. The objective of this study was to determine changes in GPX activity in the erythrocytes from the blood of farm workers. Farm workers ($n = 16$) and unexposed urban controls ($n = 8$) were recruited from local counties for this 3 year longitudinal study. Blood samples were collected once every month during the six month growing season and every alternate month in the off season. Blood was drawn in Vacutainer tubes and brought to the lab on ice. The samples were centrifuged to separate erythrocytes, lymphocytes and plasma. Aliquots of all samples were stored at $-80°C$. The activity of GPX was determined using NADPH and t-butyl hydroperoxide as substrate by a standard method. The initial results indicate a 24% increase in erythrocyte GPX activity in the blood of farm workers. This suggests a higher oxidative environment in the erythrocytes of farm workers.

Female sixth-graders receive lower nutritional benefits from lunch time intake. SUSAN B. TEMPLETON* and MARTHA A. MARLETTE, Human Nutrition Research, Kentucky State University, Frankfort, KY 40601.

We photographed trays of 355 female and 368 male sixth-graders "before" and "after" they ate lunch, then collected and weighed their leftovers. "Before" photos were compared to photos of weighed portions from sample trays to estimate initial portion size; plate waste was subtracted to calculate students' actual consumption. Nutrient content was analyzed using Nutritionist V; statistical analysis was performed using SPSS 10 for Windows. The USDA mandates that school lunches should provide 33% RDA for six nutrients—energy, protein, vitamin A, vitamin C, calcium, and iron. RDA for girls and boys age 9–13 are the same for all of these nutrients except energy; boys require an additional 250 kcal daily. Energy and vitamin C benefit did not differ by gender: girls consumed 24% of their energy RDA and boys consumed 25% RDA, including calories from competitive food items; girls consumed 47% RDA for vitamin C, vs. 50% for boys. For the other proscribed nutrients, consumption was significantly lower among girls: protein, 59% RDA vs. 71% RDA for boys; vitamin A, 17 % vs. 19% RDA; iron, 38% vs. 44% RDA; and calcium, 24% vs. 31% RDA. Lunches consumed by these sixth-grade students met the standard for protein, vitamin C, and iron; however, they did not provide the recommended levels of energy, vitamin A, or calcium for either boys or girls.

Female sixth-graders waste more cafeteria food. MARTHA A. MARLETTE* and SUSAN B. TEMPLETON, Human Nutrition Research, Kentucky State University, Frankfort, KY 40601.

We photographed trays of 355 female and 368 male sixth-graders "before" and "after" they ate lunch, then collected and weighed their plate waste. "Before" photos were compared to photos of weighed portions from sample trays to estimate initial portion size. Statistical analysis was performed using SPSS 10 for Windows. We compared initial portion sizes and percent plate waste among sixth-graders selecting items within food groups. Initial portion sizes did not differ significantly between girls and boys for fruit (113 and 112 grams, respectively), grain (both 41 grams), meat (63 and 65 grams), mixed dishes (143 and 142 grams), vegetables (70 and 101 grams), sweet snacks (39 and 45grams), salty snacks (37 and 36 grams), or other drinks (343 and 348 grams). Initial portion sizes for milk (250 grams for girls and 260 grams for boys) were significantly different at $P < 0.01$, probably due to the much higher incidence of double servings taken by boys. Plate waste for girls and boys was similar for fruits (40% and 39%, respectively), vegetables (32% and 28%), and other drinks (11% and 10%). However, girls had greater plate waste for grains (20% vs. 14% for boys), meat (23% vs. 16%), milk (20% vs. 12%), mixed dishes (27% vs. 16%), salty snacks (17% vs. 8%), and sweet snacks (12% vs. 3%), all significant at $P < 0.05$.

Evaluation of DNA damage in blood lymphocytes of farm workers during the growing season. BLAKNEY GRAY[1] and AVINASH TOPE, Nutrition and Health, Kentucky State University, Frankfort, KY 40601.

Chronic low level exposure to pesticides has been shown to cause many health conditions such as induction of oxidative stress, cytogenetic damage, and increased susceptibility to cancers in humans. DNA damage can be determined and quantified by Single Cell Gel Electropho-

resis (SCGE), also called Comet Assay. The objective of this study was to determine DNA damage in lymphocytes of farm workers who are continuously exposed to low levels of pesticides. Blood was collected once a month for six months, from June 2004 to November 2004, from farmers (n = 11) and unexposed controls (n = 8). Lymphocytes were separated on histopaque by centrifugation. An appropriate aliquot of washed lymphocytes were mixed with low melting agarose and coated on microscope slides. Cells were lysed, followed with lysis of DNA by treatment with NaOH (pH > 13.2). The fragmented DNA was electrophoresed at 40°C, at 300 milliamps, for 20 minutes, at pH > 13.2. The slides were stained with the fluorescent dye SYBR green and using LOATS software, DNA damage was determined. The initial data indicated no significant difference in tail lengths of comets from farm workers and control group.

PHYSICS AND ASTRONOMY

Thirteen years of astronomy and space science workshops. ROGER SCOTT*, RICO TYLER, KAREN HACKNEY, and RICHARD HACKNEY, Western Kentucky University, and CATHERINE POTEET, Greenwood High School, Bowling Green, KY 42101.

Beginning in the summer of 1992 a one-week Astronomy and Space Science Workshop for Kentucky science teachers has been offered at Western Kentucky University's Hardin Planetarium. The workshop has evolved over the years and includes a balance of content knowledge and teaching techniques. The presentation will include a history of the workshop, examples of activities and presentations, and photographs. Over the years the workshop has been funded by the Kentucky Space Grant Consortium (KSGC), the Eisenhower Program, and the NASA SouthEast Regional ClearingHouse (NASA/SERCH).

PSYCHOLOGY

Initial evaluation of the measurement model for the Brown ADD Scales in a non-clinical sample. TIFFANY DIEHL[1] and SEAN P. REILLEY, Department of Psychology, Morehead State University, Morehead, KY 40351.

Self report inventories, including the Brown ADD Scales, are frequently used in the diagnostic process of differentiating Attention Deficit/Hyperactivity Disorder from other related clinical disorders. Despite its widespread use, the published psychometric properties of the measurement model for the Brown ADD Scales are based in part on rudimentary statistical techniques (item-total correlations and Cronbach's coefficient alpha) and small clinical (n = 142) and non-clinical samples (n = 143). Using a non-clinical sample of 414 college students, the first independent attempt to replicate the measurement model of the Brown ADD Scales is reported. Analysis of the Brown ADD Scales using rudimentary statistical techniques yielded replicable item-total correlations that were significantly higher for item/parent scales (M = 0.60) in contrast to item/non-parent scales (M = 0.48). The latter findings were omitted from the original published data. Despite high replicable alpha coefficients (alphas ranging 0.82–0.95), the hypothesized five-factor measurement model for the Brown ADD Scales was not replicated when advanced statistical modeling techniques were employed. Specifically, a five factor measurement model yielded a poor fit for the Brown ADD Scales as estimated using maximum likelihood factoring methods and a variety of indices including the Bentler-Bonett Normed Fit Index and the Root Mean Square Error of Approximation to assess model fit. Implications for use of this instrument for assessing AD/HD symptoms are discussed.

Test anxiety and perceptions of academic skills among Eastern Kentucky college students. KRISTOPHER STEINMAN[1] and SEAN P. REILLEY, Department of Psychology, Morehead State University, Morehead, KY 40351.

Test anxiety is increasingly common on college campuses and is viewed as a major risk factor for academic underachievement, low self-esteem, and development of mental health disorders. Little is known about the prevalence and correlates of test anxiety within the Eastern Kentucky service region. Accordingly, an exploratory study was conducted to collect initial prevalence estimates of test anxiety, to identify its state and trait dimensions, and to document its relations with perceived academic skills. Thirty-two percent of 417 college students reported that they experienced significant test anxiety. Using a randomly matched control sample (n = 135), the test anxious group (n = 135) scored significantly higher on measures of trait and state anxiety. They also reported significantly poorer performance in academic areas involving oral expression, listening comprehension, basic reading skills, as well as reading comprehension, despite studying significantly more than the control group. Although additional research studies with larger samples and actual measures of academic skills are needed, the preliminary evidence suggests test anxiety may be a problem needing more attention in the regional research community.

Examination of the ASRS factor structure and convergence with popular AD/HD rating scales. MELISSA OSBORNE[2] and SEAN P. REILLEY, Department of Psychology, Morehead State University, Morehead, KY 40351.

Adult Attention Deficit/Hyperactivity Disorder is a brain-based disorder with high prevalence, serious associated health risks, and a high cost burden. Enhancing accurate detection of AD/HD is important given adults are frequently seeking treatment from primary care providers in addition to psychologists. Pharmaceutical firms have increasingly encouraged use of attention screening instruments as aids for adult AD/HD detection. To this end, Eli Lilly and Company in conjunction with the World Health Organization have created a free, narrow band attention screening instrument, the Adult Self-Report Scale-

version 1.1. To date, little published psychometric data have been reported for the ASRS-v1.1 in both non-clinical and clinical samples. Using a college sample of 330 undergraduates, an exploratory factor analysis of the ASRS suggested an alternative modeling of the two factor structure might be more appropriate. Moderate convergent validity ($r > 0.30$) was also found using subscales from the General Adult ADHD Symptom Checklist and the Brown ADD Scales. Implications for use of this instrument in AD/HD screening are discussed.

SCIENCE EDUCATION

Using DigiScope 300 (Motic Instruments) in middle school science classrooms to increase student inquiry. AMY V. MCINTOSH, Department of Biological Sciences, Eastern Kentucky University, Richmond, KY 40475.

Eastern Kentucky University is utilizing DigiScopes within ISMAM (Inquiry-based Science and Math in Appalachian Middle Schools), a GK-12 program supported by the National Science Foundation. ISMAM pairs graduate and undergraduate "fellows" in math, science and technology with middle school math and science teachers to emphasize inquiry approaches to teaching. DigiScopes were selected by ISMAM participants as a means to increase technology use and inquiry in participating science classrooms. As a result, all fellows, teachers and supporting EKU faculty were trained to use the microscopes during a 2004 summer workshop. The DigiScope 300 is a durable, inexpensive ($159) and user-friendly student microscope that has a magnification range of 20–100×. The DigiScope 300 can be used independently as a monocular field microscope or as a digital microscope when connected via a USB cable to a laptop or desktop computer. Software included with the microscope is child-friendly and enables real-time viewing of specimens via a computer monitor or digital projector. The presenter will give an overview of the microscope's capabilities and share examples of digital still and video images acquired with the microscopes. Purchasing information, software/hardware requirements, detailed instructions for navigating software and a selection of guided inquiry lesson plans will be provided.

Partnerships between university science and mathematics faculty, students, and middle school teachers: the Eastern Kentucky University model. TOM OTIENO, Department of Chemistry, Eastern Kentucky University, Richmond, KY 40475.

Eastern Kentucky University (EKU) is the home of a project titled "Enhancing Inquiry Based Science and Math in Appalachian Middle Schools" (ISMAM) supported by a grant from the National Science Foundation under its GK–12 program. The primary goal of ISMAM is to improve the teaching of science and mathematics in local middle schools. It is being implemented by placing EKU graduate or advanced undergraduate science and mathematics students into local middle school classrooms to help teachers enhance the teaching of science and mathematics through the incorporation of technology and inquiry-based instruction in the middle school curriculum. This presentation will provide an overview of the project and outline the successes and challenges experienced during the first 18 months of the project.

Float your boat: facilitating inquiry-based instruction in the middle school classroom. CHRISTOPHER A. ERVIN* and MALCOLM P. FRISBIE, Department of Earth Sciences, Eastern Kentucky University, Richmond, KY 40475, and MARGARET SOTO, Madison Middle School, Richmond, KY 40475.

An NSF-sponsored cooperative program between six Appalachian middle schools and Eastern Kentucky University (EKU) has created partnerships involving teachers, EKU faculty, and graduate/upper level undergraduate students in science and mathematics. An inquiry-based project undertaken by one of the teams targets science methodology and reasoning. "Float Your Boat" challenges pairs of students to design, build, and test aluminum foil boats to maximize cargo-carrying capability. This fall students built boats of varying designs but ultimately agreed that square designs were most effective. Participation of teaching fellows in the classroom provides an opportunity to gain valuable insights about teaching and learning about science, while offering middle school students access to effective role models.

Incorporating technology into a water quality testing experiment. TRACY L. POWELL-McCOY*, Madison Middle School, Richmond, KY 40475; JENNIFER L. FAIRCHILD and TOM OTIENO, Department of Chemistry, Eastern Kentucky University, Richmond, KY 40475.

An eighth grade science class at Madison Middle School conducts a water quality testing experiment using a commercial water monitoring kit. The kit allows one to test for parameters such as coliform bacteria, dissolved oxygen, biochemical oxygen demand, nitrate, pH, phosphate, temperature, and turbidity. The tests typically involve adding the appropriate reagent in the form of a tablet to the water sample and comparing the appearance of the mixture to a color chart. As part of our effort to infuse technology into the middle school curriculum, this presentation will discuss the measurement of some of these parameters on water samples using CBL2 data collection device. The work is part of a bigger project in which Eastern Kentucky University is collaborating with six Appalachian middle schools to improve the teaching of science and mathematics in the schools. The project is funded by the National Science Foundation.

Disabled postsecondary biology students and how they manage: an essay project. JOHN G. SHIBER, Division of Math & Science, Big Sandy Community & Technical College, Prestonsburg, KY 41653.

As an extension of a previous project with non-traditional students in eastern Kentucky, biology students with various disabilities volunteered to write personal essays

about how they were managing, or had managed, during their postsecondary education, with the hope that their stories might encourage other disabled people to enroll, or stay, in college. Others, such as family members, tutors, teachers, and/or administrators, participated in the project by offering reflections on their experiences with disabled students. Almost all the essays were very positive, poignant, and full of hope for a productive life, despite these students' unfortunate situations. Although support systems, either at home, at their rehabilitation centers, and/or at college were consistently praised, several pointed out problems they had encountered that are worthy of note: faulty or non-existent automatic doors, poorly designed restroom facilities, note-takers, tutors, and others who were not properly prepared to work with disabled individuals, etc. An occasional lack of prudent advising of certain disabled students with respect to lab courses, as observed by the investigator, and inadequate classroom and/or lab accommodations create further, unnecessary hardships for this segment of the student population, as well as for the people trying to serve them effectively. It is suggested that similar problems for disabled students quite likely occur in other Kentucky colleges and universities, and recommendations as to how these institutions might improve the *status quo* are discussed.

ZOOLOGY

Microhabitat use by lizards across three tropical islands of differing habitat density. MELISSA A. MILLER[1], CHARLES A. ACOSTA, and RICHARD D. DURTSCHE, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Island populations of lizards are limited by habitat or microhabitat availability as to where they can create their individual niche, or microhabitat. Previous herpetological surveys performed on Middle Cay, Northeast Cay and Long Cay of Belize have determined only two species of lizards (*Ctenosaura similus* and *Anolis sagrai*) to inhabit the islands. We conducted a survey during the summer of 2004 in which not only *C. similus* and *A. sagrai* were observed in abundance, but also three species of gekkonid lizard were observed as well. Due to the high density of the few lizard species found on the islands, the lizards have radiated into a range of microhabitats. On these islands, iguanid lizards were observed most frequently on rocky, sandy microhabitats while anoles optimize microhabitats of denser vegetation on the cays. Gekkonid lizards, commonly found in palm trees, shoreline conch shells, and around housing structures, are first documented for these cays in this study. This study examines the density of lizard species observed based on available microhabitat. Microhabitats were grouped as shrub, open rubble/sand, tree, grass, or artificial structure. The lizard density was determined by walking a random path (ca. one hour) around the island at approximately the same time each day. The lizards observed were noted along with the specific microhabitat that was being utilized. The encounter rate per hour was calculated in order to determine the relative densities of lizards on each island based on microhabitat. Available microhabitats were determined by parallel transects across islands (three per island) in which the percent cover of each microhabitat groups occurrence was determined. The islands surveyed in the study are ideal due to the fact that they range from low (Northeast Cay), to medium (Middle Cay), to high disturbance (Long Cay). This allowed us to not only examine lizard density based on microhabitat within an island, but also lizard densities based on overall microhabitat availability among islands of varying degrees of human disturbance.

The effects of a mixed diet in Anuran larvae. SCOTT M. GOETZ[1], MELISSA A. MILLER, and RICHARD D. DURTSCHE, Department of Biological Sciences, Northern Kentucky University, Highland Heights, KY 41099.

Anuran larvae (tadpoles) are often found to consume a range of foods. Previous studies in our lab have documented tadpoles of frogs in the family Hylidae as having a mixed diet consisting of detritus, invertebrates, and algae. Previous diet mixing studies on other species of ectotherms (e.g., turtles) have demonstrated that the nutritional benefit of certain food combinations can be greater than the sum of their parts. Upland chorus frogs (*Pseudacris triseriata*) in the family Hylidae are a wide ranging anuran species found throughout much of southern and western Kentucky. In an attempt to assess the impact on tadpoles of consuming a mixed versus a specific single diet, we examined the dietary effects of combinations of algal, detritus and shrimp diets to these foods as single-food diets in the larvae of *P. triseriata*. In feeding trials each of the aforementioned foods were presented in a "tadpole jello" individually and in combinations of each other to larvae. Various nutritional components of the diet were measured based on the fecal matter of the larval study groups. We analyzed energy content with bomb calorimetry, crude protein following Kjelldal's technique, percent organic matter from ash-free dry weight, and various macrominerals (including: Ca, P, and Mg) with color spectophotometry. Food passage rates were also measured both at the commencement and at the conclusion of the trials using fluorescent dye markers mixed into the jello. Ammonia levels were also monitored throughout the study to maintain optimal water quality.

BOOK REVIEW

Ronald L. Jones. 2005. Plant Life of Kentucky: An Illustrated Guide to the Vascular Flora. 2005. The University Press of Kentucky, Lexington, KY. xvi + 834 pages (cloth). ISBN 0-8131-2331-3. $75.00.

My botanical excursions in Kentucky began in 1971. I certainly would not have guessed then that 3.5 decades would pass before the state would get its first comprehensive flora. It is here, at long last, and the author has done a fine job of putting it together.

For 50 years E. Lucy Braun's 1943 *Annotated Catalog of the Spermatophytes of Kentucky* served as the principal checklist of the state's flora. Two guides for the northeastern quarter of North America, Gray's Manual (1950) and Gleason & Cronquist's Manual (1963, 1991), have provided additional help but their reports of Kentucky occurrences are too often vague or unreliable. In the 1970s Mary Wharton co-authored popular guides to both herbaceous and woody plants of Kentucky. A pair of updated checklists appeared in the early 1990s, one from Max Medley (1993, unpublished dissertation) and one from Edward Browne and Raymond Athey (1992, *Vascular Plants of Kentucky*).

The book under review, *Plant Life of Kentucky*, offers a wealth of data. This 834-page work covers all of the documented vascular species in the state as well 250 others thought possibly to occur in Kentucky. The introductory section (ca. 100 pages) presents, among other topics, information about the climatic and physiographic regions of Kentucky, a survey of plant communities and their characteristic species, articles on plant conservation, an overview from the standpoint of historical geology and paleobotany, and a discussion of the impact of humanity on the region. The section "A history of floristic botany in Kentucky," especially well written, covers people and events from the late 18th century to the present.

The ca. 700-page "Taxonomic treatment" is arranged alphabetically by family; these are mostly traditionally circumscribed (e.g., Scrophulariaceae), but a few (e.g., Liliaceae) are subdivided into segregate families. The keys to families, genera, and species seem to work well, at least for the dozen or so taxa that I tried. The species accounts do not include descriptions but do give authors of the scientific names, common names, flowering times, habitat, frequency of occurrence, distribution within the state (no maps are provided), and pertinent synonymy. In addition, wetland status is listed for most species.

A full 25% of the book is devoted to nearly 2000 black-and-white illustrations of plants reproduced well from the second edition of Britton and Brown's *Illustrated Flora* (a few line drawings are from other sources, including 53 originals). Doubtless the author gave careful consideration to their inclusion in a book that ultimately measures 2 inches thick and weighs 4 pounds. I personally believe that the illustrations are worthwhile because they make an otherwise technical manual accessible to novices. The plant drawings are on full, text-free pages, with nine species per page (reminiscent of Strausbaugh and Core's *Flora of West Virginia*). A rather extensive, illustrated glossary is included as an appendix.

The author, professor and curator of the herbarium at Eastern Kentucky University, has been doing field work in Kentucky and the southeastern United States for over a quarter of a century. Several of the entries given in the 25 pages of "literature cited" are of his research on plants of this region.

In a state where it is still all too easy to acquire county records, Jones's volume should go a long way towards bringing Kentucky floristics into the modern era. The book itself, hardbound and feeling quite solid, is not too big to carry in the field. With the 2005 blooming season just beginning, I am anxious to road-test it.

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NOTES

Impact of Fire on Small Mammals in a Mixed-mesophytic Forest in Southeastern Kentucky.—Extensive research has examined the impact fire has on terrestrial vertebrates. Much of this work has focused on habitats frequently exposed to fire such as grasslands, savannahs, and coniferous forests (1). Few studies have considered the impact of fire on small vertebrates in eastern deciduous forests, where fires are relatively rare. Kirkland et al. (1) conducted the only such study on how small mammals respond to fire in an 80-year-old, oak-dominated forest in Pennsylvania. For a 12-month period after a fire in November 1991, they monitored the community structure of small mammals and amphibians. Small mammals, including shrews (Soricidae) and rodents (Muridae), were significantly less abundant in burned forest than in unburned forest for the first 8 months after the fire. After that time, small mammals became equally abundant in both burned and unburned areas once woody ground litter accumulated.

In November 2001 a fire in southeastern Kentucky provided an opportunity for us to observe the response of small mammals to fire in an eastern deciduous forest. This fire occurred in an oak-dominated hardwood forest in the University of Kentucky's Robinson Forest. A total of 30 ha burned from 1 to 3 November. The fire began on the western edge of the forest and burned east. Virtually all understory vegetation, leaf litter, and woody ground litter were burned away. The bases of most canopy trees were burned; many of these trees on the west-facing slopes eventually died.

The purpose of our study was to assess the impact of fire on small mammals shortly after the fire and before any of the understory vegetation began to grow or before any woody ground litter began to accumulate. Secondly, our study provided an opportunity to compare data to the only other study known to us of the response of small mammals to fire in an eastern deciduous forest.

Robinson Forest is a 4085-ha tract of land in Breathitt, Knott, and Perry counties with the largest contiguous tract in Breathitt and Knott counties. It is comprised of a maze of deep, narrow valleys, steep slopes, and narrow, winding ridge tops with elevations from 210 to 470 m (Figure 1). The forest, second-growth and 80 years old, represents one of the largest remaining contiguously forested areas on the coal fields of eastern Kentucky. Additional information about the forest is provided by Krupa and Lacki (2). Our study took place in a 60-ha area on the western boundary of the forest in Breathitt County (Figure 1), a region of the forest with a long history of arson-caused fires (2). Throughout the history of Robinson Forest, fire has had a substantial impact on the ecology. Since 1923, ca. 80% of the forest has burned due to arson. The section surrounding Lewis Fork (including our study area) on the western boundary (Figure 1) burns most frequently due to a public access road following Lewis Fork and providing arsonists with easy access. The fire that began on 1 Nov 2001 was the most recent in the forest.

Robinson Forest is near the center of the mixed mesophytic forest region (3) with ca. 55 species of native and 6 exotic trees (4, 5). Since completion of logging in 1923, the forest has approached the composition of a mature hardwood forest, despite selected timber harvest. Our study was conducted on ridge tops in an oak-pine habitat. Chestnut oak (*Quercus prinus*) is the most dominant species; other dominants include scarlet oak (*Q. coccinea*), black oak (*Q. velutina*), white oak (*Q. alba*), shortleaf pine (*Pinus echinata*), and Virginia pine (*P. virginiana*). Blueberries (*Vaccinium* spp.) are abundant, especially where fires have occurred in the recent past.

Large sandstone rock formations from 5 to 150 m long occur on all ridge tops throughout (6); they are characteristic of our study area and are composed of complex arrangements of deep horizontal and vertical crevices. Many smaller rocks (0.5 to 5 m long) were scattered on the ground below each rock formation. Such rock formations were present on seven of the eight transects we established.

On 1 Dec 2001 we examined the burned area for evidence of mammal activity and extent of damage to understory vegetation and ground cover. On 12 Feb 2002 we constructed eight transects (four each in the burned and unburned areas; Figure 1). The transects averaged 210 m long (range = 183 to 249 m). All transects were on ridge tops in the oak-pine habitat at elevations of 435 to 469 m. Each transect was composed of 10 transect trees. From each tree, four flags were inserted into the ground to the right and left at distances of 5 and 10 m. This created 10 secondary 20-m transects perpendicular to each primary transect.

We set traps to capture small mammals on 2–3 Mar 2002 and 5–6 Apr 2002 (4 and 5 months after the fire) before understory plants began to grow and canopy trees began to leaf out. We chose these dates because the ground was still charred, covered with black ash, and without leafy or woody ground litter. Thus, the burned habitat still exhibited the fire's maximum impact. Large collapsible and non-collapsible Sherman live traps were set on the ground next to the flags of the secondary transects. Each trap was wrapped with a large plastic sandwich bag secured with rubber bands. Traps were baited with a wild birdseed mix, and ca. six cotton balls were added to protect mice from hypothermia. Traps were set from 1100 to 1600 on 2 Mar 2002 and 5 Apr 2002 and collected from 0800 to 1200 the following mornings. During each of the 2 days that traps were set, 160 Sherman live traps were set in each habitat (burned and unburned). Thus, 360 trap nights were generated each night of trapping; 720 trap nights were generated for the study.

All small mammals captured in Sherman traps were placed in a 20-liter plastic bucket for identification. Afterwards, all were released at the site of capture. Traps were

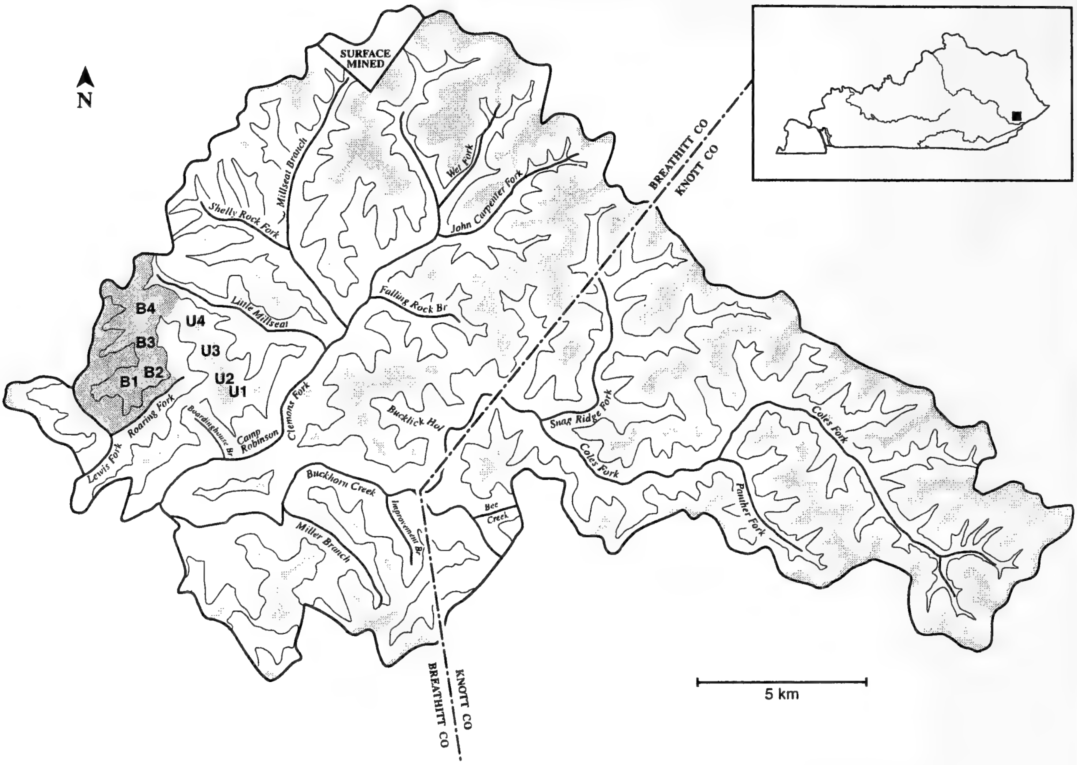

Figure 1. Map of the 4085-ha area in Robinson Forest in Breathitt and Knott counties, Kentucky. Contour lines represent 366 m elevations; the lightly shaded areas with contoured borders, 425 m elevation. The 30-ha area of forest that burned from 1 to 3 Nov 2001 is indicated by diagonal lines. Locations of the four transects in the burned area (B1, B2, B3, B4) and the four transects on the unburned area (U1, U2, U3, U4) are shown in the western portion of the forest.

cleaned and disinfected with Lysol within hours of being gathered.

Local climatological data for the trap dates were from NOAA National Climatic Data Center for the Julian Carroll Airport in Jackson, Kentucky (32 km west of the study site). T-tests for independent samples were performed using Statistica (StatSoft®).

Observations on 1 Dec 2001 revealed that the habitat of the burned forest was drastically altered. The ground was covered with black ash. Virtually all understory vegetation, leaf litter, and woody ground litter (fallen tree trunks, tree limbs, and branches) were burned away. Most old tree stumps and their roots burned, leaving deep cavities in the ground. Occasionally, small leaf piles of 2 m^2 occurred on the east sides of large rocks. Bark at the bases of most canopy trees was charred. Many large canopy trees on the west-facing slopes died a year later (Krupa pers. obs.). Shells of dead land snails (*Appalachina sayana*) were scattered over the burned area on top of the ash. These snails were not burned and apparently died after the fire. Acorns, extremely abundant, were scattered over the ground. They were not burned, indicating that they fell after the fire. Many footprints of white-tailed deer (*Odocoileus virginianus*) were found among the acorns, on which the deer apparently were feeding. Many small sandstone rocks littered the ground and were typically concealed by leaf litter. Extensive digging (presumably by small mammals) was evident in all burned areas. These freshly excavated holes were 2 to 4 cm in diameter and at least 10 cm deep. The soil excavated from them was on top of the ash, indicating that this activity occurred after 3 November.

In contrast, the floor of the unburned forest was covered with a deep leaf litter. Fallen tree limbs, small branches, and fallen trunks were abundant as were greenbriers (*Smilax* spp.), blueberries (*Vaccinium* spp.), and tree saplings (especially sassafras, *Sassafras albidum*). Small sandstone rocks were not visible. Fallen acorns and dead land snails were not found on the ground. Evidence of digging by small mammals was not apparent.

When traps were set on 2 March, the ground at the burned sites was still covered with ash, and the unburned sites still had a thick leaf litter covering the ground. No new plant growth or new woody ground litter was observed in the understory along any of the transects. Extensive sign of fresh digging was still evident on the

Table 1. Trapping results for transects on burned (B) and unburned (U) ridge tops along Robinson Forest, Breathitt County, Kentucky. Values represent number of *Peromyscus leucopus* captured out of 40 Sherman live traps per transect.

Transect	2–3 March 2002	5–6 April 2002
B1	0	14
B2	0	10
B3	0	8
B4	3	6
(Totals)	**(3)**	**(38)**
U1	9	11
U2	6	11
U3	4	11
U4	3	9
(Totals)	**(22)**	**(42)**

burned sites. Three *Peromyscus leucopus* were caught in the burned area (1.9% trap success); 22 were caught in the unburned area (13.8% trap success; Table 1). Trap success was significantly different (t-value $= -3.12$, df $=$ 6, $P = 0.02$).

A light drizzle fell much of the day of 2 March and all night (total precipitation = 1.2 cm). Overnight conditions were overcast with fog, and the wind was 15 kph from the west-northwest (280 degrees WNW). The average overnight temperature was 13°C with a low of 3°C. A full moon occurred on 27 February (3 days before trapping).

When traps were set on 5 April, conditions of the burned areas were the same as we observed in early March. No new plant growth was visible in the understory, and woody ground litter was still absent. Furthermore, none of the canopy trees had leafed out. Evidence of fresh digging in the burned area remained extensive. Essentially, the burned area underwent no visible changes since our initial visit in December 2001. A total of 38 *P. leucopus* were trapped on the burned area (23.8% trap success; Table 1); 42 *P. leucopus* were trapped on the unburned area (26.3% trap success; Table 1). Trap success was not significantly different (t-value $= -0.56$, df $= 6$, $P = 0.59$) for burned and unburned transects. One Allegheny woodrat (*Neotoma magister*) was captured adjacent to a large rock formation along transect U1 in the unburned habitat. Significantly more *P. leucopus* were trapped in April than in March (t-value $= 4.84$, df $= 14$, $P = 0.0003$).

No precipitation fell during 5 or 6 April. The night sky was clear with an 11-kph southwest wind (230 degrees SW). The average overnight temperature was 5°C with a low of 0°C. A last-quarter moon occurred on 3 April (2 days before trapping).

Of the 106 small mammals trapped during this study, 105 (99%) were *P. leucopus*. This was not surprising since *P. leucopus* is the most abundant mammal in Robinson Forest (2). Five months after the fire, this species was equally likely to be trapped in burned and unburned forest. This demonstrated that *P. leucopus* was not adversely affected by the lack of leaf litter, understory vegetation, and woody ground litter. In March, 4 months after the fire, far fewer *P. leucopus* were trapped in the burned area compared to the unburned area. Furthermore, fewer *P. leucopus* were trapped on all transects in March than in April.

Several similarities exist between our study in Kentucky and the study by Kirkland et al. (1) in Pennsylvania. Both sites were 80-year-old, oak-dominated forests that burned in November, although 10 years apart. In both cases, the understory was cleared of shrubs, leaf litter, and woody ground litter. Furthermore, *P. leucopus* was the predominant small mammal in both studies. However, results of these studies differed with respect to how *P. leucopus* reacted to the fire. In our study, *P. leucopus* was equally abundant in burned and unburned forest 5 months after the fire. In contrast, Kirkland et al. (1) found *P. leucopus* significantly *less* abundant in the burned forest 5 months after the fire. In their study, *P. leucopus* did not become equally abundant in both habitats until 8 months after the fire. They suggested that this was due to the time needed to build up woody ground litter after the fire. Presumably this ground litter had accumulated to a sufficient degree 8 months later.

Previously, Planz and Kirkland (7) demonstrated experimentally that *P. leucopus* travels over fallen tree limbs and branches and that these mice avoid areas where the woody ground litter is removed. This suggests that after the fire in Pennsylvania, *P. leucopus* left the burned habitat (as opposed to dying in the fire). However, our results suggest that *P. leucopus* in Robinson Forest relied on rock formations for refuge and was thus unaffected by the fire and did not leave. We do know that *P. leucopus* is more abundant around rock formations in the forest forest (Krupa unpublished data). The abundance of acorns after the fire and the extensive rock formations may have provided both food and protected travel, preventing death or emigration due to the fire.

The much lower trap success in March than in April in the burned area could lead to the conclusion that *P. leucopus* left after the fire and returned sometime during late March of 2002. However, it is more likely that *P. leucopus* never left. Although we lack direct evidence, it is more likely that the lowered trap success in March was the result of reduced activity, possibly caused by weather conditions. This may also explain why we captured 48% fewer mice in March in the unburned habitat. Clearly, *P. leucopus* was less active in the unburned forest in March. It stands to reason that mice in the burned area were even less active at this time but we are uncertain as to why.

In sum, our study revealed that *P. leucopus* was equally abundant in burned and unburned forest habitat 5 months after a fire burned off all existing leaf litter and woody ground cover. This is in contrast to the similar study in Pennsylvania that showed *P. leucopus* did not return until 8 months after fire once woody ground litter had accumulated. A possible explanation for the differences between the two studies was that abundant, large rock for-

mations at our study site provided protection and safe travel for *P. leucopus,* thus offsetting the need for woody ground litter typically needed for travel.

This study was a 1-semester course providing group research experience for undergraduates (BIO 395 Research in Biology). Students were involved in designing the study, collecting data, locating literature, and writing the paper. Funding was provided by grants from the University of Kentucky's Vice President for Undergraduate Studies and from the University of Kentucky Teaching and Learning Center. We thank the students in the University of Kentucky Field Ecology class (BIO 452) for assistance with trapping in April; G. Adkison for botanical assistance; W. Marshall and the Robinson Forest staff for providing data on the fire; the University of Kentucky Department of Forestry for providing housing; G. Gaber for identifying snails; K. N. Geluso for reading an earlier draft of this manuscript; and A. Fox for drawing the map of Robinson Forest.

LITERATURE CITED. (**1**) Kirkland, G. L., Jr., H. W. Snoddy, and T. L. Amsler. 1996. Impact of fire on small mammals and amphibians in a central Appalachian deciduous forest. Am. Midl. Naturalist. 135:253–260. (**2**) Krupa, J. J., and M. J. Lacki. 2002. Mammals of Robinson Forest: species composition of an isolated, mixed-mesophytic forest on the Cumberland Plateau of southeastern Kentucky. Occas. Papers Mus. Texas Tech Univ. 45. (**3**) Braun, E. L. 1950. Deciduous forests of eastern North America. Hafner, New York. (**4**) Overstreet, J. C. 1984. Robinson Forest inventory, 1980–1982, Breathitt, Knott, and Perry counties, Kentucky. Department of Public Information, College of Agriculture, Department of Forestry. Univ. Kentucky, Lexington. (**5**) Overstreet, J. C. 1989. Second-growth forest communities on the Cumberland Plateau of southeastern Kentucky. M.S. Thesis, University of Kentucky, Lexington, KY. (**6**) Krupa, J. J., J. Workman, C. M. Lloyd, L. R. Bertram, A. D. Horrall, D. K. Dick, K. S. Brewer, A. M. Valentine, C. Shaw, C. M. Clemons, J. E. Clemons, Jr., C. A. Prater, N. J. Campbell, S. B. Armold, N. J. Jones, and A. M. Clark. 2004. Distribution and habitat use of the Allegheny woodrat (*Neotoma magister*) in a mixed-mesophytic forest in southeastern Kentucky. J. Kentucky Acad. of Sci. 66: 33–38. (**7**) Planz, J. V., and G. L. Kirkland, Jr. 1992. Utilization of woody ground as a substrate for travel by the white-footed mouse (*Peromyscus leucopus*) Canad. Field-Naturalist 106:118–121.—**James J. Krupa, Terri A. Estes, Todd J. Crawford, Ann M. Schlosser, Kevin A. Chermak, Tiffany D. Justice, Devin L. Riggs, Bridget M. Larder, Justin A. Head, Heidi T. Schapker,** and **Joseph T. Forester,** Department of Biology, University of Kentucky, Lexington, Kentucky 40506-0225.

2005 Meeting of the Kentucky Academy of Science

The Kentucky Academy of Science will hold its 2005 meeting at Eastern Kentucky University on Thursday, Friday, and Saturday, November 10 through 12. (See details on our website, http://kas.wku.edu/kas/meetinginfo.asp.) The meeting is being jointly hosted by Eastern Kentucky University and Berea College. The Academy encourages faculty and student presentations and posters in all sections.

The meeting will begin with a symposium on Bluegrass Savanna Ecology on Thursday evening. Paper and poster presentations will begin on Friday morning and continue through Saturday. As in the past, undergraduate student research competitions in both oral and poster formats will be conducted on Friday. This year both paper and poster competitions will be judged by section. Winners will be recognized at the awards banquet Saturday evening. The graduate student research competition will be limited to oral presentations only.

Further details of the meeting will be available on the website and forthcoming newsletters.

Guidelines for Contributors to the Journal

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A. Original research/review papers in science will be considered for publication in JKAS; at least the first author must be a member of the Academy. Announcements, news, and notes will be included as received.

B. Acceptance of papers for publication in JKAS depends on merit as evaluated by each of two or more reviewers.

C. Papers (in triplicate) may be submitted at any time to the editor.

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List in the cover letter your telephone/FAX numbers, your E-mail address, and the names, addresses, and telephone numbers of two persons who are potential reviewers.

D. Format/style of papers must conform to these guidelines and also to practices in recent issues of JKAS, which are, in effect, a style manual.

E. Papers should be submitted in hard copy. Do not staple pages together.

F. Indent the first line of each paragraph (but not the first line of entries in the Literature Cited).

2. FORMAT

A. Papers should be in 12-point type on white paper 8.5 × 11 inches, with margins at least 1 inch all around. Double-space throughout the paper (i.e., one full line of space between each two lines of text, literature cited, or tabular data). Do not justify right margins.

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E. The first page should include the running head and, centered near the top of the sheet, the paper's title and the name and address of author(s). These should be followed immediately by the abstract. (The first page should look as much as possible like the first page of articles in JKAS.)

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G. The body of the paper should, where appropriate, include the following sections: Introduction, Materials and Methods, Results, Discussion, Summary, Acknowledgments, and Literature Cited.

H. No more than three levels of headings should be used: level 1, in capitals, centered; level 2, in capitals/lowercase, flush left; level 3, in italics, a paragraph indent, with initial capital only (except proper nouns and adjectives), and followed by a period, the text then starting after one blank space.

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B. Use no footnotes except those for title page and tables. Footnotes, identified by consecutive superscript numbers, should be entered on a separate sheet.

C. Measurements should be in metric and Celsius units. Define lesser-known symbols and give the meaning of acronyms at first use. Express time of day in the 24-hour system. Dates should be written day, month (abbreviated to three letters), year without internal punctuation. Units with multiple components should have individual components separated by a virgule (e.g., g/m^2 or $g/m^2/yr$).

D. Names of authors of binomials may be included but only at the first mention of the binomial. Cultivar names are not italicized but are enclosed in single quotes.

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4. IN-TEXT CITATION OF LITERATURE

A. Cite publications in the text by author(s) and date—e.g., (Readley 1994); multiple citations should be in alphabetical order and separated by semi-colons—e.g., (Ashley 1987; Brown 1994; Foster 1975); multiple citations of works by one author(s) should be in chronological order—e.g., (Jones 1978, 1983); publications by one author(s) in the same year should be distinguished by a, b, c, etc.—e.g., (Smith 1994a, 1994b). For in-text references to works with one or two authors use names of both authors—e.g., (Jones and Williams 1991); for works with three or more authors use name

of the first author followed by et al.—e.g., (Lee et al. 1985).

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5. LITERATURE CITED

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Lacki, M.J. 1994. Metal concentrations in guano from a gray bat summer roost. Transactions of the Kentucky Academy of Science 55:124–126.

BOOK

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PART OF A BOOK

Kohn, J.R. 1993. Pinaceae. Pages 32–50 in J.F. Nadel (ed). Flora of the Black Mountains. University of Northwestern South Dakota Press, Utopia, SD.

WORK IN PRESS

Groves, S.J., I.V. Woodland, and G.H. Tobosa. n.d. Deserts of Trans-Pecos Texas. 2nd ed. Ocotillo Press, Yucca City, TX.

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Figures must be camera-ready, glossy, black-and-white prints of high quality or laser prints of presentation quality. These should be designed to use available space effectively: a full page or part of one, or a full column or part of one. They should be mounted on heavy white board and covered with a protective sheet of paper; photographs to be grouped as a plate should have no space between them. Dimensions of plates must observe page proportions of the journal. Each illustration in a plate may be numbered as a separate figure or the entire plate may be treated as one figure. Include scale bars where appropriate. Lettering should be large enough to be legible after reduction; use lowercase letters for sections of a figure. Figure captions should be self-explanatory without reference to the text and should be entered on a page separate from the text. Number figures in Arabic numerals. Statistics presented in figures should be explained in the caption (e.g., means are presented ± SE, n = 7).

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Each table and its caption must be double-spaced, numbered in Arabic numerals, and set on a sheet separate from the text. The caption should begin with a title relating the table to the paper of which it is a part; it should be informative of the table's contents. Statistics presented in the table should be explained in the caption (e.g., means are presented ± SE, n = 7). Table should be submitted in hard copy only; they need not be included on a disk.

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